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RESEARCH REVIEW

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The RESEARCH REVIEW is a quarterly supplement published by TRAFFIC SAFETY for the reporting of research that relates to traffic safety. This service is designed to provide those who conduct research, and/or utilize research findings, information that contributes to, advances, or clarifies the body of traffic safety knowledge. The value of research and the prevention of duplication and overlap is enhanced by prompt reporting. To fulfill this purpose, the RESEARCH REVIEW will present completed reports, abstracts, summaries of research in progress, and information regarding contemplated research.

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Manuscripts appropriate for publication should be submitted to the Research Division of the National Safety Council, 425 North Michigan Ave., Chicago 11. Manuscripts cannot be returned unless accompanied by a self-addressed, stamped envelope. Editorial handling will be easier if manuscripts are typed, double-spaced in triplicate, and accompanied by an abstract of 200 words or less and all original art work. Any other information regarding research in progress or contemplated research can be submitted in any form that outlines the full particulars, i.e., investigator, problem, hypotheses, methodology, desired or expected outcomes, etc.

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. . . give me commentators plain,

RESEARCH BRIEFS

Articles in This Issue

Fletcher Platt, of the Ford Motor Company, continues his mathematical analysis of traffic safety situations. His second report, "Operations Analysis of Traffic Safety, Part 2," presents a number of equations and formulae which should prove quite provocative to research investigators. These equations and formulae have been more or less empirically determined and, as the author frankly suggests, need further testing and validating. Some readers may take issue on some of the points presented; however, this is one of the author's intentions. The author has courageously presented material which is very necessary and vital if this important aspect of research is to gain acceleration. The great deal of thought and consideration of innumerable factors that preceded this article are obvious in the presentation. It is with anticipation that we look forward to Part 3 and the conclusions of Mr. Platt's contribution.

The research group investigating crash injuries at Cornell University has been coming forth with many interesting and useful reports regarding traffic fatalities and injuries. John O. Moore in his article, "A Study of Speed in Injury-Producing Accidents: A Preliminary Report," differentiates between "traveling" and "impact" speeds. He presents a number of cases that relate the degree of injury to the impact or traveling speed. While he finds that there is a statistically significant increase in the frequency of dangerous or fatal injury as speeds increase, he points out the caution that must be observed in interpreting this finding. He indicates that associating injury with speed does not preclude association of injury with other accident injury factors. His report also treats those individuals who were ejected or not ejected from the car and the risk of injury involved in each case. He further points out the risk of various seat positions within a given automobile. Mr. Moore's study has the clear implication that speed regulation without simultaneous control of car design imposes limitations on the extent of reduction of dangerous or fatal injuries in injury-producing automobile accidents.

Oscar Richards, in his article, "Night Driving Seeing Problems," presents a very thorough and comprehensive report on what is known about vision when light is diminished. His tremendous depth of knowledge and experience is clearly apparent in his relating of many diverse scientific findings to practical applications. His suggestions to both optometrists and to motorists can prove invaluable in improving night vision. In and of itself, Dr. Richards' attached bibliography can prove quite useful to investigators in this area.

Allgaier and Williams in their report, "Effectiveness of a Driving Simulator," very neatly relate the economic factors involved in driver education. They demonstrate how the judicious use of the auto trainer can be of assistance in overcoming the expensive bugaboo of behind-the-wheel training. They exhibit findings which relate the equivalent amount of hours on the auto trainer to the amount of time taken up in practice driving. They point out that more students can be trained per period with the auto trainer with no diminution of results when the trainer is substituted for some behind-the-wheel training. This article should be of particular interest to teachers of driver education and school administrators.

Articles Appearing in Future Issues

A number of articles are presently standing in type or are in various stages of preparation for appearance in coming issues of the RESEARCH REVIEW. B. J. Campbell of the Institute of Government at North Carolina will present another part of his study on the point system entitled "The Effects of Driver Improvement Actions on Driver Behavior." Virtus Suhr and A. R. Lauer have two articles that will soon appear: "The Auto Trainer as a Measure of Driving Performance" and, "Driving Efficiency With and Without a Rest Pause." This latter is a road adaptation of the laboratory technique. Dr. William Haddon's study, "Alcohol in the Single Vehicle Fatal Accident," is also being prepared for presentation.

. . . who with no deep researches vex the brain

—G. Crabbe (1754—1832)

New Feature

Although the field of traffic safety is a fairly intimate one and many of the research investigators are familiar with or personally acquainted with one another, it has been the opinion of some that brief biographical sketches accompanied by photos of the contributing authors to the RESEARCH REVIEW would serve to improve and enhance our knowledge of and relations with one another. In this and in subsequent issues of the RESEARCH REVIEW biographical sketches will appear of the authors and contributors and, when space permits, additional biographies will be presented of the editorial board, research investigators who have made significant contributions in the field of traffic safety and others whom it is felt should be better known to the traffic safety world.

THE AUTHORS

Earl Allgaier

Earl Allgaier has been employed in the traffic engineering and safety department of the American Automobile Association since 1936. He has developed numerous teaching aids, dual controls and testing devices which are widely used in high school courses. Several have been patented. He is responsible for AAA research conducted in the field of driver education. Under his direction, teacher preparation courses are scheduled each summer in cooperation with various colleges.

Allgaier took graduate work in psychology, highway engineering and education at Iowa State College and the University of Illinois. He is a member of a number of national committees and author of various articles related to traffic safety.

John O. Moore

Mr. Moore is Director of Automotive Crash Injury Research at Cornell University. Since September, 1955, he has also been a research associate at Cornell University Medical College.

In 1936 he obtained his B.S. degree in chemistry and biology from Wake Forest College and did graduate work in biological chemistry at the Wake Forest School of Medicine and University of Michigan Medical School.

He served as Chief of Crash Injury Research for the USAF prior to joining Republic Aircraft in preventive accident design. He assumed his present duties in 1954.

He has been the author and principle investigator of many original research studies regarding crash injuries, effects of impact speeds, and is a leading advocate of seat belts in automobiles.

Fletcher N. Platt

Fletcher N. Platt has been associated with the Ford Motor Co. since 1950. He assumed his present position, manager of the Traffic Safety and Highway Improvement Department of the Public Relations and Advertising staff, in 1954.

He was born in Philadelphia in 1917 and was graduated in 1938 from the University of Michigan with a B.S. in Aeronautical Engineering. Before joining Ford, he was associated with Chance Vought Aircraft, Kaiser Cargo, Inc. and the Rheem Manufacturing Co. He is a member of the Institute of Traffice Engineers, Institute of Aeronautical Sciences and Society of Automotive Engineers.

Oscar W. Richards

Oscar W. Richards was born in Montana, received his B.A. and M.A. degrees at the University of Oregon and Ph.D. at Yale University. He taught biology and physiology at the University of Oregon, Clark University and Yale University before joining the Spencer Lens Co. Research Department in 1937.

With their centralization of research in 1950 Richards became head of the biological optics section of the research department working on human vision, vision through instruments and microscopy. His many publications are on the growth of organisms and its mathematical analysis, phase, fluorescence and interference microscopy, photomicrography and the vision problem of night automobile driving.

Samuel A. Williams

Samuel A. Williams has been teaching driver education in the District of Columbia for the past seven years. He is currently the president of the Safety Education Association of the Washington, D. C. metropolitan area.

He came to Washington from New York, where he was chairman of the Department of Health and Physical Education at the Oswego State Teachers College. He earned his Ph.D. from New York University and his master's degree from Columbia University.

He is interested in the expansion of driver education and feels that the Auto Trainer is a means whereby one teacher can teach more students and thereby cut the cost per student and that the Auto Trainer will make it possible to teach driver education in the junior high schools.

OPERATIONS ANALYSIS OF TRAFFIC SAFETY—Part II

A Mathematical Approach to Traffic Situations

by Fletcher N. Platt

This part of the report will further develop the evaluation of "Traffic Situations" by presenting empirical formulas and equations for estimating the number of events, observations, decisions, actions, errors, collisions and casualties as they might occur to a single driver under particular conditions. These formulas and equations require confirmation by new research and further analysis of established facts. They are presented with the knowledge that they are not exact, but they provide a framework within which an organized and integrated approach to the traffic problem can originate.

The method presented can be classified as a numerical approach based on average conditions. The next logical step is to study these relationships using statistical techniques in order to evaluate the effects of distribution and limits. A more complex analysis, based on linear programming, could demonstrate in more detail the interrelationship of the factors involved. However, an integrated research program to determine basic information is probably a necessary prerequisite to the use of these higher order techniques.

TABLE I

Reprinted from "International Road Safety and Traffic Review," Autumn, 1958. Part I was reprinted in the RESEARCH REVIEW, December, 1958, Vol. 2, No. 4.

A general description of each classification has been presented in Part I—"A Classification of Traffic Situations"—and will not be repeated. However, Table I, "Basic Order of Traffic Situations" from Part I is included for reference, as it is the basis of this approach.

EVENTS

General Explanation

For the purpose of analysis, events are divided into two categories, continuous and discrete. There are five groups in each category—Road Structure, Environment, Stationary Objects, Moving Objects and Events Inside the Vehicle (Reference Part I, Table III).

Events can be counted, thus the basic equations for continuous and discrete events are summations. The degree of accuracy with which events are counted will depend on the particular analysis being made. The equations presented, obviously, are only a means of approximating events if certain factors are known. For some detailed studies, however, it will be desirable to count every event.

TABLE II

NOTATION

A—Actions	a—subscript—average
B—Incorrect Actions	b—subscript—not observed by driver
C—Collisions	c—subscript—continuous function
D—Decisions	d—subscript—discrete function
E—Events	e—subscript—related to driving
F—Fatalities	f—function of
G—Design Factor	g—age
H—	h—subscript—chance
I—Injuries	i—intersection
J—Traffic Factor	j—
K—	k—possible
L—Limitation Factor	l—number of traffic lanes
M—Mass Factor	m—miles
N—Near Collisions	n—indefinite number
O—Observations	o—subscript—opposing traffic
P—Potential	p—subscript—passing maneuver
Q—Error	q—subscript—being passed
R—Density	r—traffic spacing (car lengths)
S—	s—subscript—same direction as subject vehicle
T—Total	t—time
U—Medical Factor	u—subscript—unrelated to driving
V—	v—velocity
W—Visibility Factor	w—weight
X—	x—subscript—subject vehicle
Y—Condition Factor	y—
Z—Undetermined Constant	z—
Σ—Summation	

Subscripts

1—Driver	6—Cyclists
2—Vehicle	7—Occupants of Vehicle
3—Highway	8—Obstacles
4—Environment	9—Object impacted
5—Pedestrians	

Continuous Events — General Equation

Equation I

$$(TE)_c = \sum_{o}^{n} E_c$$

If continuous events vary over the course of the study area they may be averaged or the study divided into segments as necessary. Continuous events are numbers and have no dimensions.

Discrete Events — General Equation

Equation II

$$(TE)_d = \sum_{o}^{n} E_d$$

Discrete events may be counted, approximated by formula or estimated. They may be non-dimensional but usually should be tabulated as a number per mile.

Events—Tabulation (Table III)

The total number of events should be tabulated separately as Continuous Events and Discrete Events per mile. They should also be divided into events relating to the driving task and those that are unrelated, by sense modality.

These classifications will be necessary in the next step of the procedure, evaluating driver observations.

Events that take place due to moving vehicles are so complex that a series of empirical equations have been developed to assist in estimating them.

One Way Traffic, Constant Velocity

Equation III

$$E_c = 21\left[\frac{v}{10r}\right]$$

Explanation:

1. Driver must watch a minimum of 2 vehicles in each lane (in front and in the rear).

TABLE III

"SAMPLE TABULATION OF EVENTS"

(Reference Part I Tables III and VII)

Continuous Events	VISUAL		KINESTHETIC		STATIC	
	Related to Driving	Unrelated	Related to Driving	Unrelated	Related to Driving	Unrelated
Road Structure—						
Width of Pavement	1					
Curb Lanes and Shoulders	1					
Lane Markings	1					
Surface Roughness	1		1		1	
Environment— (Details)						
Moving Objects—						
Vehicles	1					
Inside the Vehicle— (Details)						
Total Continuous Events	5		1		1	
Discrete Events per mile						
Road Structure— (Details)	15	22	5			
Environment— (Details)	8	31				
Stationary Objects— (Details)						
Moving Objects—						
Vehicles	40					
Pedestrians	10	50				
Animals	2	5				
Cyclists	4	1				
Inside the Vehicle—						
Passengers		3				
Sounds			25			
Controls						
Inertia Forces					5	10
Total Discrete Events	79	112	30		5	10

Other Sense Modalities should be tabulated as required. (Ref. Part I, Table VII)

2. As the driver and traffic moves faster, he must watch farther ahead and behind. Assume he must consider one vehicle length for each 10 miles/hour. $\left(\frac{v}{10}\right)$.
3. As spacing between vehicles gets smaller, the greater the number of vehicles the driver must watch. Therefore, the number of events are proportional to $\left(\frac{1}{r}\right)$.

Example: $v = 40$ m.p.h., $r = 5$ car lengths, $l = 1$ lane

$$E_s = 2 \times 1 \left[\frac{40}{10 \times 5} \right] = 1.6 \text{ events}$$

One Way Traffic, Passing Other Vehicles

When the subject vehicle is on a one-way street with two or more lanes, passing maneuvers usually occur. A passing maneuver will be considered an event, and will depend on several factors. Separate equations are written for three velocity relationships (Equations IVa, IVb and IVc).

Equation IVa

when $v_s > v_x$

$$(E_d)_{sp} = \frac{R_s}{v_x} \left[.85(v_s - v_x) + 1.5 \right]$$

These equations are based on the assumption of a velocity distribution of the traffic stream of 15% travelling 10 m.p.h. faster than v_s. If the distribution is known, the equations can be modified accordingly.

Explanation:

1. The number of passing maneuvers per mile will be proportioned to the density of traffic.
(R_s)
2. On the basis of the velocity distribution assumed, when $v_s > v_x$, the number of vehicles passed is proportional to the following equations:

$$.85\left(\frac{v_s - v_x}{v_s}\right) + .15\left(\frac{10}{v_s}\right)$$

when $v_x < v_s$ Equation IVb

$$(E_d) = \frac{.15R_s}{v_s} \left[10 - v_s + v_x \right]$$

Explanation:

1. The number of passing maneuvers per mile will be proportional to the density of traffic
(R_s)
2. With the velocity distribution assumer, and $v_s < v_x$, the subject vehicle will pass no more than
$.15R_s$
3. The number of vehicles passed per mile will also be a function of v_s and v_x.

$v_s = v_x$ Equation IVc

$$(E_d)_{sp} = \frac{1.5R_s}{v_s}$$

Explanation:

1. When $v_s = v_x$ then the subject vehicle will pass all vehicles travelling below v_x.

$$.15R_s\left(\frac{10}{v_s}\right)$$

One Way Traffic—Being Passed by other Vehicles

Derivations of these equations are similar to the three preceding ones and thus explanations will not be given.

When $v_s > v_x$ Equation Va

$$(E_d)_{sq} = \frac{.15R_s}{v_s} \left[10 - v_s + v_x \right]$$

When $v_s < v_x$ Equation Vb

$$(E_d)_{sq} = \frac{R_s}{v_s} \left[.85(v_x - v_s) + .15(10 + v_s) \right]$$

TABLE IV

ESTIMATE OF EVENTS AT INTERSECTIONS

Subject Vehicle Direction	Right Angle Intersections	Possible Events (E_t)			
		Vehicles	Pedestrians	Signs	Total
Straight North	No Traffic Control	11	2	0	13
"	Stop signs North and South	9	1	1	11
"	Stop signs East and West	8	2	1	1
"	Traffic Signal Control	6	1	2	9
"	Signal and no Left Turn	4	1	3	8
"	Signal and no turns	3	1	3	7
Right turn	No Traffic Control	8	2	0	10
"	Traffic Signal	5	1	2	8
Left turn	No Traffic Control	12	2	0	14
"	Traffic Signal	8	1	2	11
	Tee Intersection				
Approaching	Turning Right	5	2	0	7
Dead-end	Turning Left	7	2	0	9
	Driveway				
Straight ahead	Drive on right	6	.0	0	6
"	Drive on left	5	0	0	5
	Limited Access				
Entering					5
Exiting					4

When $v_x = v_s$ Equation Vc

$$(Ed)_{op} = \frac{1.5R_s}{v_x}$$

Two Way Traffic—Passing or Being Passed in Same Direction

The equations for passing or being passed in the same direction are the same for both one- and two-way traffic. However, the passing maneuver is limited in two-way traffic by:

visibility factor (W)
the velocities—(v_x) subject vehicle
—(v_o) opposing traffic
the density of opposing traffic (R_o)

An empirical formula can approximate this limitation.

Equation VI

$$(E_d)_{op} + (E_d)_{eq} \leq \left[\frac{70{,}000W}{(v_x + v_o)^2} \right] - R_o$$

The factor W can vary from 0 to 1.0 depending on highway design and environmental conditions.

Two Way Traffic—Oncoming Vehicles, No Passing

Equation VII

$$(E_d)_o = l_o R_o \left[1 + \frac{v_{ox}}{v_x} \right]$$

Explanation:

1. The number of vehicles passed will be the density per lane mile times the number of lanes.
   $l_o R_o$
2. As the traffic in the opposing lanes is moving as well as the subject car, the number of vehicles passed per mile travel will be greater than $l_o R_o$ by the ratio of the velocity of the opposing stream to the velocity of the subject vehicle.
   $\left[\frac{v_{ox}}{v_x} \right]$
   With all other factors constant, the number of oncoming vehicles passed will decrease as the velocity of the subject vehicle increases.

Examples:

$(ER)_o = 1 \times 20 \left[1 + \frac{60}{30} \right]$ $l_o = 1$ lane, $R_o = 20$ vehicles/lane mile, $V_x = 60$ m.p.h., $V_o = 30$ m.p.m.

$(ER)_o = 20 \times 3 = 60$ events/mile

$(ER)_o = 1 \times 20 \left[1 + \frac{60}{60} \right]$ $l_o = 1$ lane, $R_o = 20$ vehicles/lane mile, $V_o = 60$ m.p.h., $V_x = 60$ m.p.h.

$(ER)_o = 20 \times 2 = 40$ events/mile

The next logical step in analysis is the case of opposing traffic only, travelling at random velocities. However, in this case the same number of vehicles would pass the subject vehicle and passing on a two or three lane highway depends on the density and velocity of traffic, travelling in both directions (not just one). If the subject vehicle is travelling on the inner lane of an undivided highway, the events due to opposing traffic would be the same as a two lane, two direction highway.

Two Way Traffic—Oncoming Vehicles Passing Each Other

A very important consideration is that of two way traffic with oncoming vehicles passing each other. These maneuvers assumed to be limited to the following factors:

a visual factor (W) (range from 0 to 1.0)
the velocities (v_x) subject vehicle
(v_o) opposing traffic
the density of the traffic (R_s) in same direction as subject vehicle

An empirical formula can approximate this limitation.

Equation VIII

$$(E_d)_{op} \leq \left[\frac{70{,}000W}{(v_x + v_o)^2} \right] \left(\frac{40}{v_x} \right) - R_s$$

Two Way Traffic—Passing on Three Lane Highway

Three lane highways require special consideration. The limitations of passing or being passed in the same direction can be approximately as follows:

Equation IXa

$$(E_d)_{op} + (E_d)_{op} \leq \left[\frac{70{,}000W}{(v_x + v_o)^2} \right] \frac{R_o}{2}$$

Passing maneuvers of oncoming traffic will be limited by:

Equation IXb

$$(E_d)_{op} \leq \left[\frac{70{,}000W}{(v_x + v_o)^2} \right] \frac{R_o}{2}$$

Intersections

The number of intersection events will depend on the type of intersection, the degree of traffic control and the number of cars entering the intersection. Events per mile, obviously, will be the summation of events for each intersection in each mile.

Equation X

$$Ed = \frac{1}{m} \sum_{1}^{T_i} (i)\ (E_i)$$

The value (E_i) will be determined below for a typical intersection to demonstrate the procedure. See Table IV.

Right Angle Intersection No Traffic Control

Subject vehicle X proceeding west. The numbers indicate the possible conflicting maneuvers by vehicles. Each one will be considered an event. Pedestrian conflicts will be considered as noted.

OBSERVATIONS

Introduction

The observation of events is recognized as an important factor in the sequence of driver activity. Table I illustrates this step, with "Observations Related to Driving," "Observations Unrelated to Driving" and "Unobserved Events" as the three direct derivatives.

Further study indicates this to be a complex relationship which must be evaluated in order to establish quantitative values. Table V illustrates the factors that will be considered.

Discussion of Observations

In most cases, an event related to the driving task will be observed more than once by good drivers. On the other hand, some events may not be observed at all. The approximate number of Potential Observations will depend on the particular event and so two tables, VI and VII, have been prepared to relate Continuous and Discrete Events with Potential Observations. The factors used are estimates and should be replaced by more accurate values when determined by experiment. Sense modalities have also been assigned to each type of event for use in the subsequent analysis.

Potential Observations

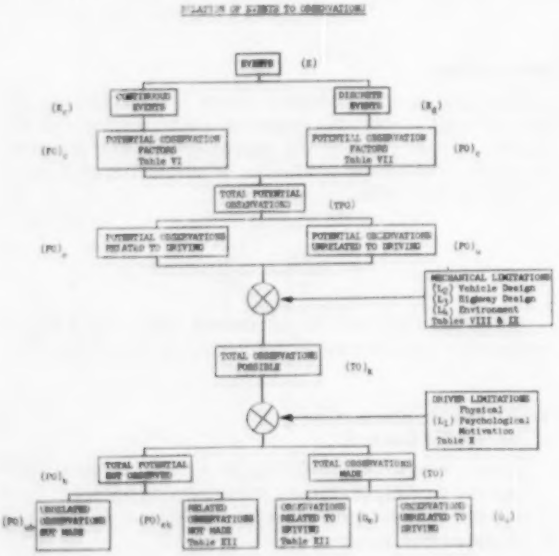
Events should individually be multiplied by the proper factor in order to establish the total number of potential observations.

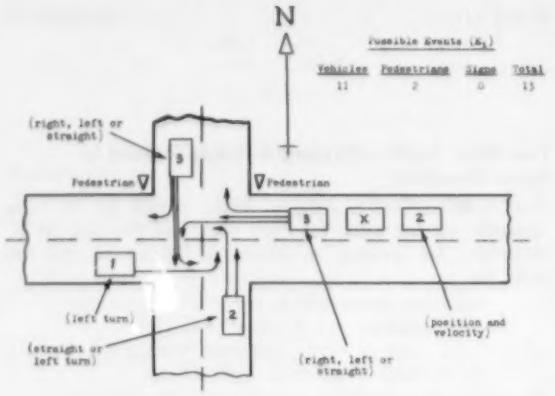
Equation XI

$$(TPO) = \sum E_c(PO)_c + E_d(PO)_d$$

These should not only be broken down into each sense modality but also divided into potential observations required for safe driving and potential observations unrelated to driving.

TABLE V





To this point, the determination of observations has dealt only with the total potential observations, without consideration of the mechanical limitations of a particular situation.

The following steps will establish the mechanical limitations of observation due to vehicle, highway and environment and then predict the actual number of observations made by the driver to the driving task.

Possible Observations

Both related and unrelated observations will be limited by vehicle design, highway design and environment. Within each sense modality a rating factor (0.0 to 1.0) should be estimated for vehicle design limitations, maintenance limitations, highway design and for environment. (Table VIII and Table IX). Judgment should be exercised in assigning factors for each component relating to the particular sense modality.

For instance, forward vision in vehicle design is probably several times as important as rear vision. Therefore, the windshield area and wiper are more important in establishing a rating than is the rear window. Headlights should have no rating for a daytime study but would rank high as a night driving factor.

The lowest of the rating factors for the vehicle, the highway or the environment should be used in determining the Possible Observations. The lowest factor for each sense shall be multiplied by the number of potential observations in each sense modality and the result will be the number of Observations Possible.

Equation XII

$$(TO)_k = (TPO)\ \ (L(\text{min.}))$$
(for each sense modality)

In other words, Possible Observations are those observations, in each sense modality, that could be made under existing circumstances by a fully alert, experienced driver.

Driver Limitations—Physical

In addition to the driver's choice of observations, there are limits to his ability to observe. And this ability differs greatly between individuals.

TABLE VI

RELATION BETWEEN CONTINUOUS EVENTS AND POTENTIAL OBSERVATIONS

Continuous Events	Type of Observation (Sensory Process)	Estimated Equivalent Discrete Observations $(PO)_e$	
		Per Minute*	Per Mile
Road Structure			
Width of pavement	Visual		)
Curb and shoulder	"		) 30
Lane markings	"		)
Surface roughness	"		)
Environment			
Sun glare	Visual (Limiting)		
Darkness	" "		
Rain or snow	" "		
Fog, haze, smoke	" "		
Snow, ice, sand, on road	Visual		(included above)
Odors	Olfactory	2	
Wind and other sounds	Auditory	2	
Moving Objects			
Vehicles	Visual—Fwd.		(included above)
(same direction and velocity)	Visual—Sides		2
	Visual—Aft.		5
Inside the Vehicle			
Driver—Mental distractions	——	1-10	
Hunger, thirst	Organic	0-2	
Fatigue	"	0-10	
Sleepiness	"	0-20	
Pain, discomfort	Pain	0-5	
Temperature	Thermal	0-2	
Humidity	"	0-2	
Touch	Tactual	1-2	
Taste	Gustatory	0-2	
Passengers (affecting driver)	Auditory	0-5	
Sounds (Vehicle)	"	0-2	
Radio	"	0-10	
Control motions and forces	Kinesthetic	0-5	
Vehicle motion (equilibrium)	Static	0-2	

* Convert to observations per mile by multiplying by $\frac{60}{v}$

Also, as a result of transient factors (fatigue, illness, drugs, alcohol) one person's ability changes to a marked degree from time to time. Table X establishes the major factors to be rated relating to the limitations of the driver.

Driver Limitations—Psychological

What are the general principles relating to man's ability to observe? The following are assumed to be generally true:

1. Man can make continuous observations in each of the sensory modalities simultaneously.
2. Within any modality, he must choose to divide the time of continuous observations between all of the continuous events that occur.
3. Any one or more of the senses may be unresponsive.
4. Attention may be focussed on only one discrete event at a time.
5. There is finite limitation (although it may vary) on the number of discrete events that can be observed at a given time.

Limitations of the driver could be divided into segments to advantage if data were available. Specific limitations for observations, decisions and actions separately would help evaluate the problems related to drivers' capabilities under various driving conditions. Response times shown in Table XI include all three factors and are typical of the information available in the basic tests in psychology.

For purposes of this discussion, however, assume that the observation time of finite stimuli is 1/3 of the measured simple response time (Table XI.)

These estimates give finite limitations* for discrete observations in each important sense modality as follows:

Auditory—20/second
Visual—16/second
Kinesthetic—12/second
Static—5/second

As stated earlier, these observations can occur simultaneously.

If an observation is in the realm of previous experience, habit may take over and a conscious decision may not be necessary. Many driving experiences fall into this category.

Driver Limitations—Motivation

The driver has a choice of the observations he makes within the limits of conditions and his ability. For example,

* Obviously, these limitations are on gross observations, not, for instance, the detection of sound at 10,000 CPS or the difference in wave length of different colors.

TABLE VII

RELATION BETWEEN DISCRETE EVENTS AND POTENTIAL OBSERVATIONS

Discrete Events	Type of Observation (Sensory Process)	Estimated Potential Observations per Event $(PO)_4$
Road Structure		
Horizontal Curves	Visual	2
Vertical Curves	"	2
Surface Hazards	"	2
Traffic Signals and Intersection	"	3
Traffic Signs	"	2
Lane Markings	"	2
Intersecting Roads (No signal)	"	3
Guard Posts and Rails	"	1
Obstructions (Visual)	"	1
Environment		
Sun Glare	Visual (Limiting)	2
Light Glare	" "	2
Rain or Snow	" "	2
Fog, Haze, Smoke	" "	2
Wet Roads	"	2
Snowy or Icy Roads	"	2
Sand or Gravel	"	2
Wind	Auditory	2
Stationary Objects		
Parked Vehicles	Visual	3
Trees	"	1
Abutments	"	1
Signs (Advertising)	"	1
Moving Objects		
Vehicles—Moving	Visual (All direct.)	2
Overtaking	"	3
Passing	" (Fwd or Aft)	4
Pedestrians	"	2
Animals	"	2
Cyclists	"	2
Inside the Vehicle		
Driver—discrete distractions		1
Passenger—adults	{Auditory	1
children	{Tactual	3
Sounds	Auditory	2
Control Motions and Forces	Kinesthetic	2
Motion and Inertial Forces	Static	1

he might choose to observe the scenery (unrelated to driving) rather than read traffic signs. He might listen to the radio with only limited attention to the traffic around him. It is obvious that motivation of the driver plays an important role in the Total Observations Made within the limitations already established. More needs to be known about driver motivation and how adequate attention to the driving task can be maintained.

TABLE VIII

OBSERVATION LIMITING FACTORS — VEHICLE DESIGN AND MAINTENANCE (L_2)

Sense Modality

Visual—
- Roof and Pillar structure
- Glass—area, distortion, tinted
- Rear view mirrors—size and location
- Windshield wiper
- Windshield washer
- Windshield defroster
- Headlights
- Reflection characteristics

Kinesthetic—
- Position and action of steering controls
- Position and action of brakes
- Position and action of accelerator
- Seats

Static—
- Ride characteristics (springs, tires, center of gravity, etc.)
- Skid characteristics (loss of control)

Auditory—
- Wind noise
- Heater noise
- Engine noise
- Tire noise (road-tire combination)
- Radio
- Windshield wiper

Thermal—
- Heater
- Windows
- Air vents
- Air conditioner

Others—
- Relatively unimportant

Note:

(L_2) Should be estimated from 1.00—perfect observation characteristics, to 0.1—extremely poor characteristics, on the basis of the factors listed above.

Examples:

A convertible with top down would have a high visual rating.

A panel delivery truck without adequate windshield wipers and rear view mirror could be rated 0.1 to 0.2 in vision.

Observations Made

The actual observations made will depend not only on the limitations that have just been discussed and the driver's motivation, but to some degree on the intensity* of the particular stimulus. For instance, a siren, a relatively fast-moving object or flashing sign will increase the observation response.

It is impossible to be specific on the observations that will be made by a particular driver under specific conditions, but it would be useful to know what most drivers observe related and unrelated to the driving task. This is obviously one of the keys to driver actions and driver education methods. Total Observations Made will be the total Observations Possible times the Driver Limitations:

TABLE IX

"OBSERVATION LIMITING FACTORS—HIGHWAY AND ENVIRONMENT"

(L_3) (L_4)

Sense Modality	Considerations
Visual	Light Conditions
	Daylight
	Dawn or dusk
	Night (dark or light)
	Direct sun
	Headlights
	Street lights
	Weather
	Fog
	Snow
	Rain
	Other obstructions
	Smoke and haze
	Physical obstructions
	Buildings, trees, poles, fences
	Road structure—hills
	Advertisements
	Traffic
Kinesthetic	Road roughness
Static	Road design
	Undulations, bank curvature
	Altitude
Auditory	Road-tire combination
	Traffic
Olfactory	Smoke
	Other odors
Thermal	Temperature
	Humidity
Tactual	Clothing
	Seat covering

Note:

(L_3) (L_4) Should be estimated from 1.00—perfect conditions, to 0.1—extremely poor conditions, on the basis of the factors listed above.

TABLE X

OBSERVATION LIMITATIONS—DRIVER—PHYSICAL

(L_1)

Sense Modality	Considerations
Visual Sense	Gross Optical Qualities
	Physical Limitations—Eye, head, body movements
	Training—Scanning and focussing
	Time Limitations—(vehicle velocity)
	Velocity—blurring of vision
	Light adaptation
	Transients—
	fatigue
	illness
	drugs
	alcohol
	illusions
All other Senses	Physical handicap
	permanent
	temporary
	Limit of ability
	Endurance
	Time Limitations
	Transients—(as above)

Note:

(L_1) Should be estimated from 1.00—perfect conditions, to 0.1—extremely poor conditions, on the basis of the factors listed above.

TABLE XII

SUMMARY TABLE OF OBSERVATIONS

Sense Modality	Observations Related to Driving (O_e)	Potential Observation Related to Driving (PO_e)	Related Observations Not Made (PO_{eb})
Visual	80	110	30
Kinesthetic	11	15	4
Static	8	10	2
Auditory	3	7	4
Others	—	—	—
Total — per mile	102	142	40

Reference: Table V

Equation XIII

$$(TO) = (TO)_k(L_1)$$

Driving Observations Not Made

Observations related to the driving task that are not made must be determined in order to estimate the number of chance errors. This can be obtained by subtracting the number of Driving Observations Made from the number of Potential Related Observations Not Made (Table XII).

Equation XIV

$$(PO)_{eb} = (PO)_e - O_e$$

DECISIONS

It can be assumed that every observation of the driver relates to a decision of some kind. For example:—

1. Discard—take no action.
2. Take action immediately.
3. Retain information momentarily:
   — to compare at later time.
   — to take action later.
4. Retain information permanently:
   — experience.

Time is required to make decisions, and the limitations will depend on vehicle velocity, as well as mental capacity and alertness of driver. Many decisions require several observations, such as judging the speed of an oncoming car in order to pass, or estimating the degree of curvature of the highway ahead.

It will be assumed that on the average, two observations will be required for each decision*.

* The number of observations required per decision will be on the same order as the number of potential observations required per event (Table VII).

TABLE XI

REFERENCE TABLE ON RESPONSE TIMES
(Observation, Decision, Action)

Sense Modality	Simple Response Mean Time	Estimated Times*		
		Observation	Decision	Action
Auditory	0.15 seconds	.05	.05	.05
Visual	0.20 "	.06	.07	.07
Kinesthetic (Muscle Sensitivity)	0.25 "	.08	.08	.09
Static (Equilibrium and Body Position)	0.60 "	.20	.20	.20

Notes:
— Response time increases with mass of body movement and complexity of movement (up to 3 times).
— Response time increases with the number of stimuli
Approximate Response = [Simple Response + (0.8 × number of stimuli — 1)]
— Response time increases with increasing number of tasks
Approximate Response = (Simple Response × Number of tasks).
— Response time increase with the increased difficulty of the perceptual task.
(Up to 5 times simple response for accommodation, recognition and response)
— Response time increases with increased complexity and difficulty of judgment task.
For example: Judge speed of oncoming car — 1.5 seconds
Start of pass — 2.5 to 3.5 seconds.

* Made by the author.

Equation XV

$$TD_s = \frac{(TO)}{2} = \frac{(O_e + O_u)}{Z}$$

Decisions relating to driving will be:

Equation XVa

$$D_e = \frac{O_e}{Z}$$

On the basis of a limit of two observations per second, plus judgment time of one second, decisions will be limited to one every two seconds, or 30 per minute.

Equation XVb

$$D_s < 30\left(\frac{60}{v}\right) < \frac{1800}{v}$$

ERRORS

Once in a while every driver makes an error of driving judgment. On the basis of the author's observation (and not experiment) it is estimated that an average driver will make at least one error in each 40 decisions. The number of errors is also a function of the physical and mental condition of the driver and his driving experience*. Assuming the best drivers will make only one error for every 100 decisions, the equation for driver errors will be:

TABLE XIII

CONSTANTS FOR CONDITION OF DRIVER (Y_1)

Physical Condition
Well and Alert — 0.8-1.0
Tired or Ill — 0.5-0.8
Several Drinks or Under Medication — 0.2-0.5
Under the "influence" — 0.1-0.2

Mental Condition
Concentrating on Driving — 0.8-1.0
Worried about other matters — 0.5-0.8
Upset — 0.3-0.5

Experience and Training
Driver Training plus 5 or more years of experience —0.8-1.0
No Training, several years' experience — 0.3-0.5
No experience — 0.1-0.3

Equation XVI

$$Q_1 = \frac{D_e}{100(Y_1)}$$

Chance Errors

When a driver does not observe certain specific events related to the driving task, there is a reasonable chance that an incorrect action could result(*). The odds could be of the magnitude of one in five of this occurring.

The equation for chance errors will be:

Equation XVII

$$Q_h = \frac{(PO)_{eb}}{5}$$

Obviously, this equation is a guess, but ways may be suggested to establish a rational solution.

ACTIONS

For simplicity, assume that an action is a coordinated body effort (steer, accelerate, brake or signal) resulting

* A recent letter from Fred W. Hurd, Director, Yale University Bureau of Highway Traffic, states in part:—
"The rate at which hazards occur over a period of time seems to 'set the stage' for driver performance. It is this that makes some of our most hazardous roads safe and, when intermittent, contributes to the element of surprise. You will recall, accident records have indicated that roads with partial control of access are more hazardous than those with full control or without any control. Furthermore, a sharp curve at the end of a tangent is far more hazardous than the same curve as a part of a curving alignment."

from a single decision. Then:

Equation XVIII

$$A_x = D_x = D_e + D_u$$

There will also be a limitation on actions because of the elapsed time of reaction. Assuming reaction time for any action is ½ second, plus 2 seconds for each decision, then the limit of actions will be one every 2½ seconds or 24 per minute.

Equation XVIIIa

$$A_x \leq 24\left(\frac{60}{v}\right) = \frac{1400}{v}$$

This is based on average situations. In emergencies, actions could occur more rapidly for a brief period. Related to driving the equation is

TABLE XIV
CONSTANTS FOR CONDITION OF VEHICLE AND ROAD SURFACE
(Y_2, Y_3)

$Y_2 =$ Condition of Vehicle
- New=0.9-1.0
- 1-2 Years=0.7-0.9
- 2-4 Years=0.6-0.8
- 5-10 Years=0.2-0.5
- Over 10 Years=0.1-0.2

$Y_3 =$ Condition of Road Surface
- Dry, Smooth=0.8-1.0
- Dry, Rough=0.7-0.9
- Wet=0.4-0.6
- Snow=0.2-0.3
- Ice=0.1-0.2

Equation XVIIIb

$$A_e = \frac{D_e}{3}$$

Incorrect Actions

Incorrect actions result from driver errors and from chance errors.

Equation XIX

$$B = Q_3 + Q_h$$

When actions related to driving are limited by time (Equations XVa and XVIIIb) some required actions may not be taken. These should be considered as additional error factors.

Results of Incorrect Actions

Incorrect actions can result in three possible situations:

1. No dangerous results.
2. Near collisions.
3. Collisions.

NEAR COLLISIONS

The major causes of near collisions are the lack of understanding between drivers, a driver and pedestrian (loss of communication), loss of vehicle control or some combination of these factors.

Loss of communication is a function of density of vehicles and pedestrians, while the loss of control is some function of the experience of the driver and condition of the vehicle, and environment. The velocity of the vehicle obviously is also a very important factor.

The equation for the number of near collisions with other vehicles or fixed objects will be:

Equation XXa

$$N_1 = \frac{f(g_1)B}{Z(Y_2+Y_3)}\left[(v_x + v_o)d_o + (v_x \pm v_{ss})d_s + v_x d_b + v_x\right]$$

↑ opposing traffic; ↑ traffic same direction; ↑ fixed objects; ↑ roll-over

The equation for near collisions relating only to pedestrians is:

Equation XXb

$$N_2 = \frac{f(g_1\, g_2)B}{Z(Y_2+Y_3)}\left[v_x\, d_b\right]$$

The equation for near collisions relating to cyclists is:

Equation XXc

$$N_3 = \frac{f(g_1\, g_3)B}{Z(Y_2+Y_3)}\left[v_x\, d_b\right]$$

Figure 1 is an example of the information available that can be used to approximate the effect of driver age on Near Collisions, $f(g_1)$ in Equation XXa.

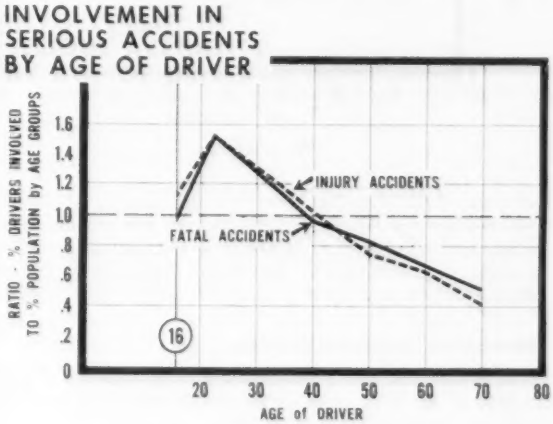


FIGURE 1

COLLISIONS

Collisions may be classified as a special case of near collisions. The same factors apply and it is estimated that the average rate of collisions is of the magnitude

Equation XXI

$$C = \frac{N}{125}$$

INJURIES

Number of Occupant Injuries

The probable number of vehicle occupant injuries is some function of occupant exposure, (C_7), the number of occupants per vehicle, (d_7), the design of the vehicle, (G_8), the relative velocity of impact, ($v_x \pm v_9$), and mass and energy absorption characteristics of the object struck (M).

Equation XXIIa

$$I_7 = Z(c_7 d_7)\left(\frac{1}{G_2}\right)\left|(v_x \pm v_v)M\right|$$

Crash tests have been made by Ford Motor Company to determine the passenger compartment deceleration under various conditions *(Fig. 4)*. A Cornell Crash Injury Research study indicates the relationship of dangerous and fatal injuries of occupants to impact velocity *(Fig. 3)*.

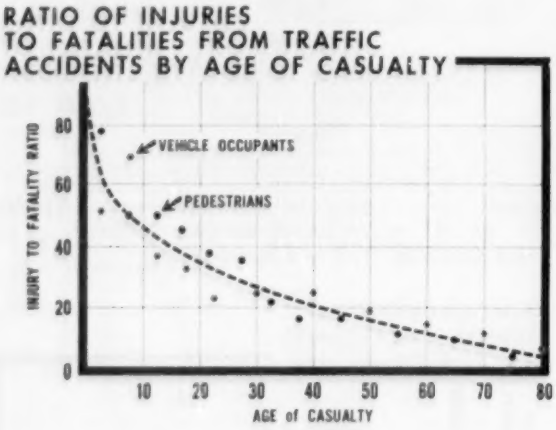


FIGURE 2

Neither of these curves, however, are directly applicable for establishing factors in the equation, but are shown as examples of the type of information that can be useful in making approximations. Refinement and correlation of these kinds of data could provide a more accurate solution.

Number of Pedestrian Injuries

It is assumed that a pedestrian will be injured to some degree if hit by a motor vehicle. A review of accident statistics supports this approximation.

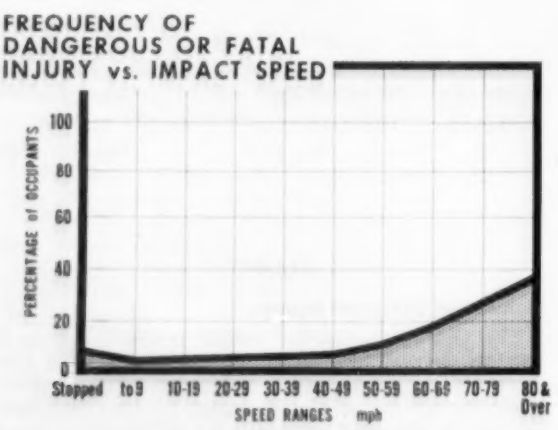


FIGURE 3

Equation XXIIb

$$I_8 = C_8$$

Number of Cyclist Injuries

It is assumed that cyclists also are injured to some degree if involved in a motor vehicle collision.

Equation XXIIc

$$I_6 = C_6$$

FATALITIES

Number of Fatalities

The number of fatalities can be estimated based on the number of injuries, the severity, age of victim and extent of medical care received.

Occupants

Equation XXIIIa

$$F_7 = \frac{I_7\left[(v_x \pm v)M\right]}{ZU\,(90 - 20\sqrt[4]{g_7})}$$

Pedestrians

Equation XXIIIb

$$F_8 = \frac{I_8 v_x}{ZU\,(90 - 20\sqrt[4]{g_8})}$$

Cyclists

Equation XXIIIc

$$F_6 = \frac{I_6 v_x}{ZU\,(90 - 20\sqrt[4]{g_6})}$$

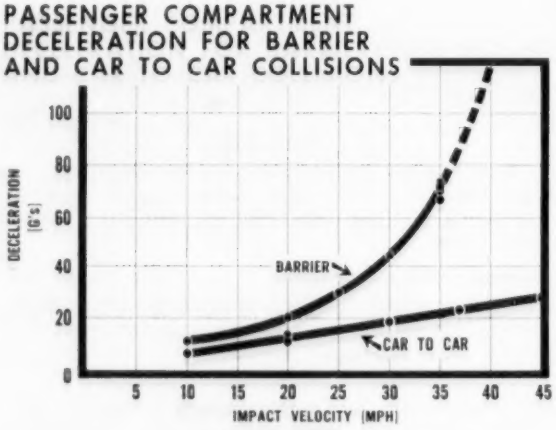


FIGURE 4

Explanation: Severity of Injuries

This factor is the same as used in the injury equation and thus the fatalities related to velocity and mass, a square function.

$(v_x \pm v_v)M$ (for occupants)

(v_x) (pedestrians and cyclists)

TABLE XV

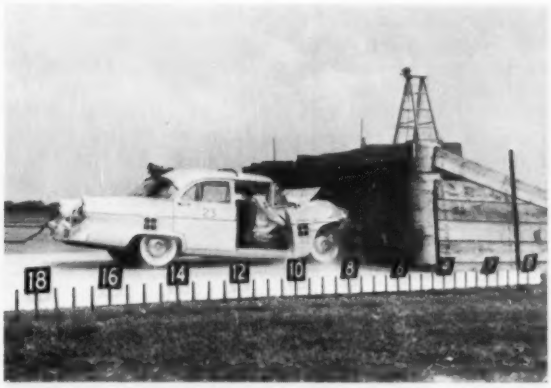
DESIGN FACTORS — FOR OCCUPANT INJURIES

G_2 = Vehicle Design Factor
- Based on current data from Cornell Crash Injury Research
- 1956 and later model=0.8-1.0
- 1955 and earlier model=0.4-0.7

(M) = Mass Factor
- Large weight compared to vehicle=1.0
- Same weight as subject vehicle=0.5 ($w_x = w_0$)
- (Decrease factor with increase in energy-absorbing characteristics)

(v_0) = Velocity of Object Impacted
- Fixed object $v_0 = 0$
- Vehicle moving toward subject vehicle ($v_x + v_0$)
- Vehicles at right angles $v_x + \frac{v_0}{2}$
- Vehicles moving in same direction ($v_x - v_0$)

Note: The mass and velocity factors together are consistent with the following fact: When two vehicles of equal weight, traveling at the same velocity meet head-on, the resultant damage to each vehicle is approximately the same as one vehicle hitting a fixed object at the same velocity.



Barrier crash test to determine decelerating forces as a function of impact velocity under laboratory conditions.

Age of Victim (g)

Estimate from pedestrian accidents in Detroit and Michigan accidents in 1956. Equation is

$$1/F = \frac{1}{(90 - 20\sqrt[4]{g})}$$

See Figure 2 for method of determination.

Medical Care (U)

This factor might partially account for higher fatality rates at night, and in some areas of the country where facilities are farther apart.

Best care — 0.9-1.0
No care — 0.1-0.2
Includes:
- Time before treatment
- First aid
- Ambulance care
- Emergency Room care
- Surgery, etc.

CONCLUDING STATEMENT

In Part II, the author has established a series of equations and limits for the evaluation of traffic situations, taking into account the major factors involved. There are obviously many factors that have been roughly approximated or omitted from the equations presented. Completed research in specific areas, but unknown to the author, may be available for a better selection of constants and equations.

Part III of this series of articles, will present an evaluation of important factors and their inter-relationships and a discussion of how the formulas can be used. It will also outline the areas of research that are needed and their relative importance in accident and casualty analysis.

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A STUDY OF SPEED IN INJURY-PRODUCING ACCIDENTS

A PRELIMINARY REPORT

by John O. Moore

Automotive Crash Injury Research of Cornell University is a medical and statistical group which, over the past five years, has conducted basic research into the generic aspects of automobile accidents and their resultant injuries. At present, data are collected from the national highways with the cooperation of local police, medical, and public health groups in 17 states and two cities. Analysis of the data revealed patterns of preventable injury which led to changes in automotive design. Subsequent data indicate that these have led to reduced occurrence and severity of injury in accidents. Such changes are represented by padded instrument panels and sun visors, recessed hub steering wheels, strengthened door locks, and automobile seat belts.

It is expected that a continuation of the present approach will provide a satisfactory definition of both the crash injury problem as a whole and the importance of individual segments, such as the relation of speed to injury, the relation of design to specific types of injury, and the type of medical care necessary for the injured. These segmental problems may then be subjected to further, intensive study.

This report investigates the common assumption that fatal injuries sustained during automobile accidents are associated with high speed and that if speed were rigidly controlled, fatal crash injury could be eliminated. On the one hand, there is a constant reiteration that "Speed kills . . . Slow down and live!"; while on the other hand, it is obvious that greater speed and mobility are increasingly being introduced into our culture. Thus, there appears to be an insoluble contradiction: the increase of speed and the belief that speed is a deadly menace. It is strange that such a situation should exist since the contention that "speed kills" has never been actually proved. It is the purpose of this preliminary study to examine data which may throw light on the subject of the relationship between speed and injury or death.

There is little doubt that the "high" or "excessive" speed of a traveling automobile can cause an accident; as the speed increases, so does the rate of closure, thereby reducing the time available for visual and motor responses to accomplish their objectives. The cause of injury, however, is another matter, for all accidents do not necessarily produce injury.

This study originally appeared in the "American Journal of Public Health," Vol. 48, No. 11, Nov. 1958.

This paper examines accident and injury data on 3,203 automobiles involved in injury-producing accidents to determine effects which speed may have had on the frequency of dangerous or fatal injuries in such accidents.

The examination consists of four substudies: (1) the frequency distributions of the cars according to "traveling" and "impact" speeds in progressive ranges of 10 mph; (2) the frequency of dangerous or fatal injury in each of the progressive "traveling" and "impact" speed ranges; (3) the extent to which rigid control of "traveling" speed would reduce the frequency of dangerous or fatal injuries in injury-producing accidents; and (4) the influence which factors other than speed (ejection, seat area occupied, site of impact) have on the incidence of dangerous or fatal injuries.

Materials and Methods

An interstate cooperative program involving police, highway patrol personnel, physicians, and public health authorities in over 17 states and two cities produces Automotive Crash Injury Research data through the use of detailed photographs and specially designed accident and injury forms. Sampling technics control the reliability and representativeness of the data. State police and highway patrolmen are specially trained by project personnel in investigative, reporting, and photographic procedures. Hospital emergency room staffs and physicians in the areas sampled are also briefed on the program and public health or similar authorities act to secure complete, detailed, and accurate medical reports. All persons participating in the program are oriented and motivated toward the requirements of a study aimed at complete fact-finding concerning accident-injury factors, as well as accurate identification of the specific and structural causes of injury.

Definition and Discussion of Terms

Realistic examination of the relationship between speed and injury or death requires a distinction between traveling* speed and impact† speed. For example, the driver of a car traveling at 60 mph may foresee an accident, apply his brakes, and finally strike an object at 40 mph. Thus a

*Traveling speed: the speed of the car just before involvement in an accident.

†Impact speed: the speed at which the major impact occurred between the car and object(s) or other car(s) or vehicle(s).

chain of events leading to the possibility of an injury is created: a particular traveling speed results in an accident involving a particular impact speed; the injury observed, although related to both the traveling and impact speeds, is more closely related to the latter, while the occurrence of the accident is related to the former. This study, therefore, while examining the relationship between speed and death or serious injury, will keep data on traveling speed distinct from that on impact speed.

One of the difficulties in dealing with speed data is that speed reporting is sometimes subjective. Objectivity in this field of study would require speed recording instrumentation in every automobile, or very large-scale employment of radar or similar devices. Since neither of these methods is used presently for research—nor promises to be in the immediate future—reliance must be placed on the accuracy of speed reporting by police and highway personnel.

These professional accident investigators have had years of experience in estimating speeds through observation of many thousands of traveling cars; they are trained in the proper methods of interpreting accident details and use such evidence as the extent of basic car damage, tire condition, skid marks, types of road surface, weather conditions, and related information in determining accident speeds. Also, recent years have seen the development of tests to measure and improve the accuracy of police and highway personnel in estimating rates of closure. Thus, although most current speed reporting is partly subjective, the subjectivity is being progressively minimized. Speed data reported to Automotive Crash Injury Research has the additional advantage of support and confirmation through photographic evidence. Experienced accident analysts at the project's headquarters in New York City use detailed pictures of car damage to corroborate reported traveling and impact speeds.

Portions of the report which follow deal with the implications that certain speeds are "excessive" or "above limits." Of course, speed limits in one area of the country often differ from those in another because of variations in terrain, road design, traffic density, and so forth. Nevertheless, an arbitrary definition of what speed is "excessive" can be based on the knowledge that large segments of our present rural highway systems actually employ a speed limit of 60 mph. Thus, for purposes of discussion, this study deals with an arbitrary speed "limit" of 60 mph and refers frequently to speeds above or below this "limit."

Observations

Basic Data for Study

Each of the 3,203 passenger automobiles studied was involved in an accident during the period from 1953 to 1956 inclusive, and contained at least one injured person. Every type of accident is represented and the total sample resembles national registrations of passenger automobiles in terms of makes, models, and years of manufacture.

The 3,203 cars carried 7,154 occupants, or 2.3 persons per car. Among the 7,154 occupants various degrees of injury were sustained in the following proportions:

	Per cent
No injury	25
Minor injury (bruises, minor lecerations, etc.	46
Nondangerous injury (severe lacerations, fracture, etc.)	20
Dangerous injury (internal, brain injuries, etc.)	5
Fatal injury (death instantaneous or within 24 hours after accident)	4

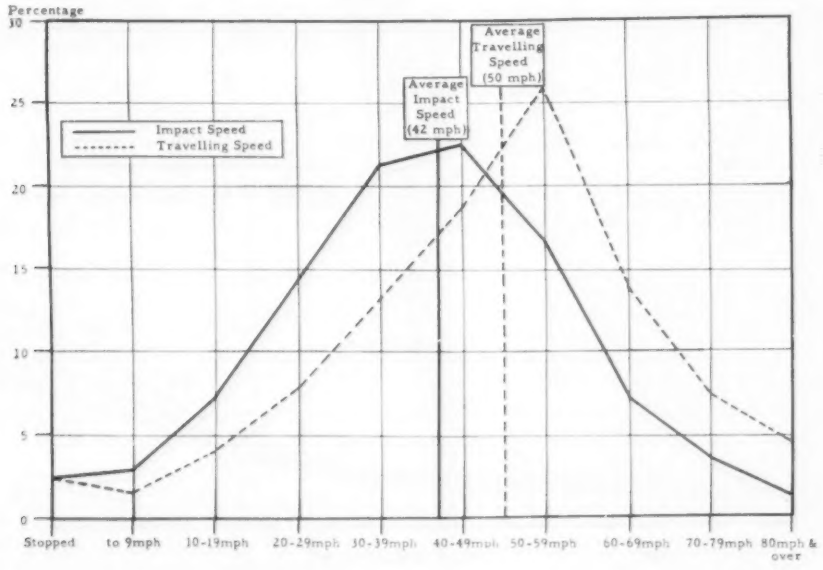

Figure 1—Distribution of Reported Traveling and Impact Speeds Among 3,203 Cars in Injury-Producing Accidents.

Reported Traveling Speeds and Impact Speeds of Automobiles in Injury-Producing Accidents

Figure 1 shows the distribution of the 3,203 cars according to both reported traveling and impact speed. It will be seen immediately that the greatest proportion of these cars were traveling at speeds in the 50-59 mph range and impacted in the range of 40-49 mph. Calculation shows that the average traveling speed was 50 mph and the average impact speed 42 mph.

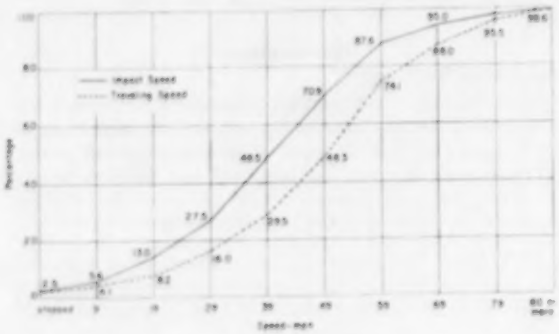

Figure 2—Percentage of Cars Traveling or Impacting at or Below a Specified Speed.

The basic regularity of the distribution curves in Figure 1 establishes an important fact: the majority of injury-producing accidents studied were not associated with the higher speed ranges as popular opinion would have led us to expect. Cars in injury-producing accidents appeared in all ranges of speed and arranged themselves in the typical bell-shaped distribution curve.

In Figure 2 the speed data are presented in cumulative fashion, showing that 16 per cent of the cars traveled at 29 mph or less, 29.5 per cent traveled at 39 mph or less, 48.3 per cent traveled at 49 mph or less, etc. Combining data on the cars which traveled at the most "common" speed (50-59 mph, as shown in Figure 1) with data on the cars which traveled at lesser speeds, we find that a total of 74.1 per cent of the 3,203 cars studied had been moving at speeds under 60 mph before becoming involved in injury-producing accidents.

Similar consideration of impact speed as opposed to traveling speed tells much the same story. The bulk of the cars impacted in the lower speed ranges. The cars which impacted at the most "common" impact speed (40-49 mph, as shown in Figure 1), combined with all the cars impacting at lower speeds, comprise a total of 70.9 per cent of the 3,203 cars.

Occurrence of Dangerous or Fatal Injuries as Related to Speed in Injury-Producing Accidents

Figure 3 shows what proportion of the persons impacting at successive speed ranges suffered dangerous or fatal injury. (Such injuries were sustained by 9 per cent of the total occupants in the cars studied.) These two grades of injury (representing trauma which placed car occupants either on hospital "critical" lists or in morgues within 24 hours) are used in this study to measure the effect of speed in automobile accidents; they reflect the severest aspect of injury. Measuring the effect of automobile accidents by the occurrence of fatal injuries only, while dramatic, illustrates merely a portion of the problem. That large segment of the population which is injured to a dangerous degree also represents a major problem. The

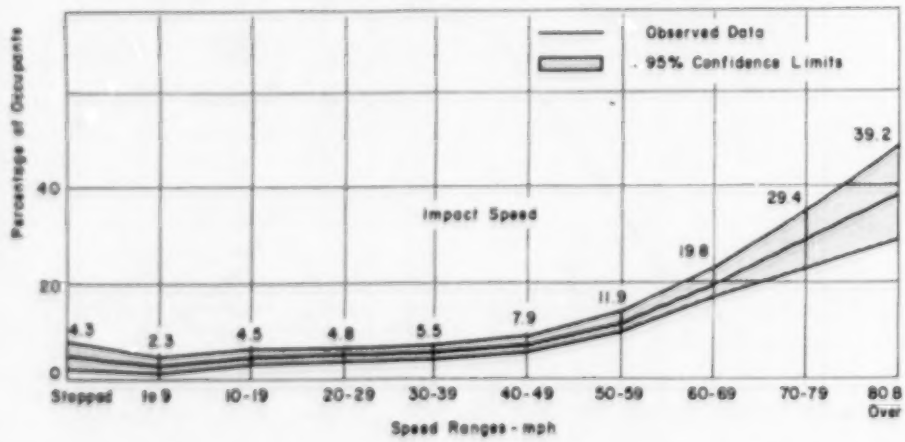

Figure 3—Frequency of Dangerous or Fatal Injury According to Progressively Higher Ranges of Impact Speeds.

loss of manpower and dollars through hospitalization, treatment, and often permanent disability has become a critical matter not only to industry, but also to the military services and the medical profession. Injuries of lesser degree—often including those of a painful, disfiguring, or disabling nature—are, of course, also important and will be dealt with in a subsequent study.

Analysis of data on injury-producing accidents shows that as traveling and impact speeds increased there was a steady and statistically significant increase in the frequency of dangerous or fatal injury. However, as Figure 3 indicates, injury increases were relatively small in speed ranges up to and including 40-49 mph. From the 50-59 mph range, as the traveling or impact speeds increased, the frequency of dangerous or fatal injury became more marked; the frequency finally rose to nearly 28 per cent among persons traveling at or above 80 mph and to approximately 40 per cent among persons in cars impacting at or above this speed.

The finding of association between the occurrence of dangerous or fatal injury and increasing speeds must be viewed with caution. Association of injury with speed does not preclude association of injury with other accident-injury factors. Aside from this, the speed data must be interpreted in terms of how many cars or people are involved. For example, only 4½ per cent were traveling at or above 80 mph, and no more than 25 per cent were traveling at or above 60 mph.

Keeping in mind the important observation that high speeds are relatively infrequent, we can proceed to examine the differences in risk of dangerous or fatal injury in injury-producing accidents according to whether the speed was above or below an arbitrarily selected limit. In this examination, the observations are restricted to the traveling speeds because these are more readily subject to control than impact speeds.

Since the most commonly reported traveling speed in injury-producing accidents was in the 50-59 mph range, we arbitrarily use 60 mph as our dividing line and can proceed to observe the frequency of dangerous or fatal injury among persons who were in accidents while traveling above or below this speed.

Tabulations showed that about 6 per cent of the occupants of cars involved in accidents while traveling at speeds up to 60 mph sustained such injuries; above this speed the toll was in the order of 17 per cent. Thus, it might be said generally that in the injury-producing accidents studied traveling above 60 mph was associated with a nearly three-fold increased risk of dangerous or fatal injury.

The findings at this point must, once again, be treated with reservation. What has been discussed has been risk if involved in an accident without regard to frequency. Further, there exists a distinct possibility that factors other than (or concomitant with) speed acted to create dangerous or fatal injury. Simultaneous consideration of risk and frequency can be accomplished by means of "expectancies."

Discussion

Occurrence and Expectancy of Dangerous or Fatal Injury as Related to Speed Regulation

For purposes of discussing speed regulation, a speed of 60 mph is used here, too, as the dividing point for comparison. Although authorities in the field of accident prevention emphasize the need for public education concerning the hazards of "excessive speed," it should be repeated that only 25 per cent of the cars in this study of injury-producing accidents were reported to have been traveling at speeds exceeding 60 mph before involvement in the accidents. Thus, it is evident that efforts devoted exclusively to speed regulation cannot be expected to solve the problem of dangerous or fatal injuries in automobile accidents with any degree of completeness.

Since even a small reduction in the frequency and severity of injury is immediately desirable and since the data presented show an association between speed and injury, some improvement in the injury picture can be achieved through speed regulation. Nevertheless it should be recognized that speed is but a single factor associated with injury in accidents and that other factors may be even more significantly associated. Although the risk of a dangerous or fatal injury in the injury-producing accidents studied increased markedly at the "top" speeds, both the risk and frequency of distribution of dangerous and fatal injuries must be taken into account in answering the vital question: "To what extent can rigid control of traveling speed reduce the current toll on the highway?"

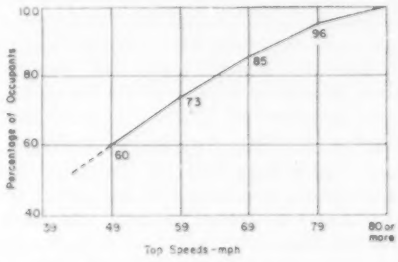

Figure 4—Expected Percentage of Dangerous or Fatal Injury at Specified Top Speeds.

To answer this question the method of "expected values" was used. In essence, the purpose of this method was to secure a gross estimate of what would have happened had rigid speed controls been enforced during the time when these data were collected. The procedure entailed certain assumptions: (1) every vehicle traveling above the specified "rigid speed limit" would, instead, have been traveling at that speed; (2) the risks for the individuals "moved down" by this rigid speed limits would have been the same as the risks of the individuals actually traveling at this limit in the study; (3) other factors would not have changed. For example, the reduction in speed would not have changed anything about the accident and there would have been the same number of people, cars, types of accidents, and so forth. Under these assumptions, it was pos-

sible to gain a gross estimate of the dangerous or fatal injuries which presumably would have occurred if the speed in these injury-producing accidents had been rigidly controlled to a specified limit.

The expected percentages (Figure 4) show that if the speed limit had been rigidly fixed at 79 mph (by some miraculous 100 per cent control), then 96 per cent of the dangerous or fatal injuries would still have occurred. If the limit had been restricted to 69 mph, then 85 per cent of the injuries would nevertheless have occurred. Similarly, a top limit of 59 mph would have yielded 73 per cent. Even if the rigid speed limit had been reduced and held to 49 mph, there would have resulted an essentially limited reduction in the number of dangerous or fatal injuries, for 60 per cent of the dangerous or fatal injuries would still have occurred. Hence, while rigid speed control of the top speeds would be expected to produce some improvement in the injury picture, there seems to be a definite limit to the amount of improvement that can be achieved by absolute speed regulation.

Other Factors Influencing Injury

It has been indicated that speed is not the sole element in producing dangerous or fatal injuries. Certainly there are accidents of such unusual and extreme circumstances that no efforts—reduced speed or any type of designed safety engineering, such as seat belts, harness, padding, and others—can avail in avoiding serious injury or death. Collisions with immovable barriers often represent this type of accident—which fortunately accounts for a relatively small proportion of the injury-producing accident situations observed. Further, analysis by the "expectancy" method has indicated that speed control offers only partial solution to the problem of these injuries. Granting that there is no injury if there is no accident and that "excessive" speed may have a bearing on whether or not an automobile accident occurs, speed control nonetheless would seem to imply accident prevention more than injury prevention.

Previous studies have revealed several accident factors (other than speed) associated with the occurrence and seriousness of injury in automobile accidents; three of these factors will be discussed briefly here. One is the phenomenon of ejection, which takes place most frequently when doors open under impact conditions. The consequence of doors opening—it has been established that front doors open in about 50 per cent of cars in injury-producing accidents—is that ejection occurs among approximately 13 per cent of the total car occupants. The profound effects of ejection on injury are shown in Table 1. Dangerous or fatal injuries were sustained by five times as many ejectees as non-ejectees, i.e., ejection multiplied the risk of dangerous or fatal injury by five.

Table 1—Risk of Injury as Related to Ejection or Nonejection

	Percentage of Occupants with			
	Moderate Through Fatal Injury	Severe Through Fatal Injury	Dangerous or Fatal Injury	Fatal Injury
Nonejectees	23.9	9.9	5.5	2.6
Ejectees	49.9	36.1	26.6	13.3
Injury ratio, ejectees to nonejectees	2.1:1	3.7:1	4.8:1	5.1:1

Another factor bearing upon the production of dangerous or fatal injuries relates to the specific areas of the car occupied by passengers. Table 2 shows the frequency of dangerous or fatal injury among occupants of various seat areas.

Although the problem of injury as a function of the seat area occupied is a subject for further and more thorough study, the table clearly shows that the likelihood of receiving a dangerous or fatal injury was widely different among the occupants of various seats. These differences were found to be statistically significant. Generally speaking, the entire rear seat area was less "dangerous" than the front seat area. Further, the dangerous or fatal injury potential of the right front seat was somewhat (although not remarkably) greater than that of the driver's seat.

Table 2—Risk of "Dangerous" or Fatal Injury According to Seat Area Occupied

Seat Area Occupied	Percentage of Occupants with Dangerous or Fatal Injury
Driver*	7.5*
Center front	4.9
Right front	10.4
Left rear	4.7
Center rear	5.2
Right rear	6.4

*Since the Automotive Crash Injury Research sample is one of injury-producing accidents, a driver alone in a car must be injured to get into the sample. To eliminate bias overempnasizing driver injury this table shows frequency of injury among drivers who were accompanied by passengers.

Another influence on the occurrence of dangerous or fatal injury is the area of the car sustaining the principal crash impact. To examine this influence it was necessary to study the frequency of injury among occupants with respect to their proximity to the site of impact. Table 3 shows the wide variations in injury frequency which occurred according to interaction of (1) the location of the impact; (2) the seat occupied; (3) the "closeness" of the seat area to the impact site.

The data show that being near the impact site produced the greatest likelihood of dangerous or fatal injury, regardless of seat occupied; further, the incidence of the injury varied as a function either of the site of impact or the seat area occupied.

It has been shown that injury may be associated with many accident factors which can be controlled by engineering and design. Ejection, the force localization dictated by objects in a given seat area, and the energy-absorbing qualities of various exterior portions of the car are all subject to effective control through engineering. Undoubtedly

there are other factors, not yet isolated or discussed here, which may relate to injury cause and may also be controlled by design engineering. It should be realized that such factors often may relate to one another. Similarly,

Table 3—Risk of "Dangerous" or Fatal Injury According to Occupants* Proximity to Crash Impact Site

Relation Between Occupant and Crash Impact Site	Area of Car Sustaining Principal Impact	Percentage of Occupants with Dangerous or Fatal Injury	
		Drivers	Right Front Seat Passenger
Opposite impact site	Front	5.6	7.4
At or near impact site	Side	16.7	20.0
Opposite impact site	Side	2.0	8.5
No strict relationship (car rolled over)	Top	3.1	4.5

*Based on nonejected occupants of cars involved in injury-producing accidents.

each of these factors may also be related, in some degree, to speed. For example, clinical observation showed that ejection increased as speed increased, or that in a given seat area the frequency of injury increased as speed increased. However, an all-important reservation is that dangerous or fatal injuries increased appreciably from one speed range to the next, starting at the traveling speed range of 50-59 mph. In the lower traveling speed ranges, while there were increases in risk of dangerous or fatal injury, these increases were rather small. However, despite the lower risks of dangerous and fatal injury associated with traveling speeds under 60 mph, it must be recalled that these risks were encountered by the occupants of nearly 75 per cent of the cars studied. In consequence, the actual number of dangerous and fatal injuries observed in this group is just about equal to the number of such injuries among the much smaller group—25 per cent—where occupants were exposed to the higher risks associated with speeds in excess of 60 mph.

An estimation of the part which speed plays in producing dangerous or fatal grades of injury must take the above findings into consideration. The data clearly indicate that the role of speed is a supporting one.

Years of study in the field of automobile crashes have clearly established the fact that an essential causal element associated with injury in an automobile accident is the nature of the object which the human body strikes and what part of the body is involved. Clinical observation clearly indicated that increasing speed could increase the frequency or severity of injury, but that speed as a factor was of lesser importance than the object inflicting the injury. Further, it was apparent that the design of objects which might be struck could be influenced and controlled with a directness and a permanence not possible where speed is concerned. This hypothesis was justified by repeated observation that some objects, when contacted, easily inflicted injury at almost any speed, and that other objects, when contacted, produced no injury except at relatively high speeds. These clinical observations and hypothetical opinions can now be placed in proper perspective through the statistical procedures adopted in analyzing the data for this study. Data analyses have clearly indicated that control of speed has serious limitations in terms of reducing injuries, because it affects only a proportion of the cars, but that design engineering affects injury in all cars and in all speed ranges. Thus, efforts to reduce dangerous or fatal grades of injury in automobile accidents must take the factors of speed and design engineering into simultaneous consideration.

Summary

A study of the reported impact and traveling speeds of 3,203 cars in injury-producing accidents and correlation with injury data on the 7,154 occupants of these cars revealed:

1. Approximately 74 per cent of the cars involved in injury-producing accidents were traveling at speeds under 60 mph and about 88 per cent involved impact speeds under 60 mph.

2. In injury-producing accidents there was a statistically significant association between increases in both traveling speed and impact speed and the frequency of dangerous or fatal injury. In each of the 10 mph traveling speed ranges through 59 mph the increases in frequency of dangerous or fatal injury were slight; beyond 59 mph the increases rose sharply. Among the occupants of cars traveling above 59 mph (represented by 25 per cent of the cars observed), the frequency of dangerous or fatal injury was nearly three times as great as it was among the car occupants traveling below 59 mph.

3. Complete and absolutely controlled top speed limits would afford relatively limited reduction in the expectancy of dangerous or fatal injuries in injury-producing accidents; strict maintenance of a top traveling speed of 49 mph would still have seen the occurrence of 60 per cent of the dangerous or fatal injuries.

4. Many factors other than speed operated to produce injury in automobile accidents. Acting independently, interdependently, or together with speed were such accident factors as ejection, seat area occupied, and site of crash impact.

5. In the bulk of injury-producing accidents dangerous or fatal injury in low speed ranges—except where ejection occurred—appeared to be very largely a function of the shape and form of interior car components, whether these were struck, and what parts of the human body struck them; such injuries in the higher speed ranges apparently associated with an interacting combination of both the dynamic results of speed and the design of the car.

6. Speed regulation without simultaneous control of car design imposes limitation on the extent of reduction of dangerous or fatal injuries in injury-producing automobile accidents.

NIGHT DRIVING SEEING PROBLEMS

by Oscar W. Richards

Most traffic accidents occur at night. Analyses of accident statistics have failed to relate them to faulty vision, yet driving is largely a reaction to visually obtained information. From the biological viewpoint, humans driving at night are working at a task for which they are poorly equipped. Nocturnal animals have specialized eyes for seeing with little light and they do not compete in daylight. While our eyes can adapt to a large range of light, they see less well as darkness comes and have no specialization for after dark life. A brief look at our night vision problems shows a considerable loss in seeing that may explain the nearly doubled night traffic accident rates.

At dusk seeing becomes difficult. The sky is still quite bright while objects on the road seem to merge with their shadows and fade in the darkness. The overhead brightness veils the field of view with glare that prevents the retina from adapting enough to use efficiently the small amount of light reflected from the roadways. Parking, or low beam lights aid in placing vehicles, but high beams add to the veiling glare and should not be used. Clues to stimulate the two eyes into fused binocular vision, become fewer with deeper twilight and more strain is placed on the muscular coordinating mechanism of the eyes. It is important to have the best possible correction for any phorias or muscular deficiencies of the motorist's eyes. The glare and smaller amount of visual information, handicaps judgment of depth, and of position and speed of vehicles. At twilight objects seem to be farther away than their actual distances.[37] With greater darkness, changes appear more rapid and momentary, and a second look for rechecking becomes less and less possible.

With darkness the broad fields of view of daylight close in to the region illuminated by the headlights, the overhead glare vanishes, and the eyes adapt to the prevailing light level of the headlights. Unless there is moonlight, or other lights, no more can be seen than that lighted by the headlights of the cars on the road. The presence of other cars may either help or hinder vision and heavy traffic can lessen the road illumination by a fourth. In urban regions the greater lighting provides larger fields of view with unequal, concentrated and distracting information which varies randomly, moment to moment.[37]

The night driving fields of view are smaller, the visual content of the field changes rapidly and the information received is more concentrated. Values change, colors fade, resolution decreases, pattern predominates, even when it is poorly defined, and large objects must be recognized from a patch or smear of light or shadow. No information is obtained from subliminal fields which appear as blind areas in the somatic field. Close objects are seen directly by the light they reflect, but, depending on the available light and their reflectance, when they are from 25 feet to a half block away they can be seen only in silhouette against the slightly brighter surround. A large area like the back of a truck may be seen before a small, dirty, although slightly brighter, tail light is visible. Transition zones at tunnels or ends of brightly lighted streets are dangerous unless so lighted as to ease the adaptation of the eyes.

Decreases Away From Headlights

Seeing becomes less possible away from the main beam of the headlights; the eyes tend to search for a more sensitive part of the retina to help interpret the blurred images and the world appears unreal and ghostly. As Blackwell has aptly said, night presents a new geometry. The searching movements and the adjustments of the pupil increase fatigue.[37] Some drivers tend to stare fixedly which can lead to fatigue, and fascination which can paralyze a normal response to a dangerous situation. Others may be so dis-

Read before the annual meeting of the American Academy of Optometry, Chicago, Illinois, December 7, 1957. For publication in the November, 1958, issue of the AMERICAN JOURNAL OF OPTOMETRY AND ARCHIVES OF AMERICAN ACADEMY OF OPTOMETRY.

tracted in the rapidly changing scene that they cannot drive properly without a marked reduction of speed. Again, on the lonely country road there may not be enough stimulation to keep a tired driver awake. Truck drivers who have slept all day may survive, while a tired motorist having worked all day may not survive, or even worse, may injure others from failure to keep in his lane.

In daylight the driver is told to watch the big picture, two blocks ahead, or a half mile ahead in the country, but at night there is no large picture and it is risky to look afield. The small fields, reduced still more by speed, may lead to overconfident driving from failure to see enough.

How big is the field of view? Weston[37] considers it to be 5° × 8°, Figure 1. The figure shows the field, rectangle A, at 1200 feet, based on Nagel's pictures[30] of the experimental illumination on the 72 feet wide Connecticut Turnpike.

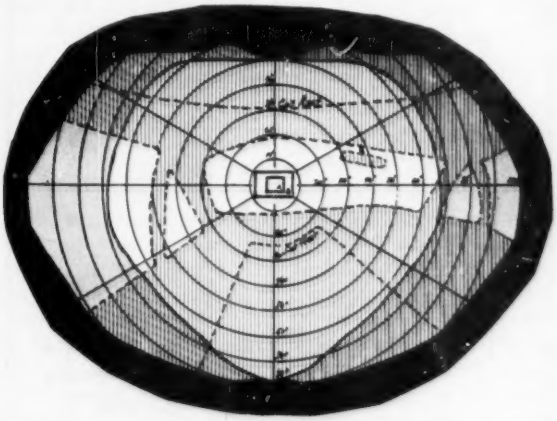

Fig. 1. Comparative fields of view seen by a motorist. The binocular field is not stippled. Regions blocked out by the auto are marked with vertical lines. A, is the field of a 72-foot road at 1200 feet and B, is Weston's 5 x 9 degree night driving visual field.

Lower cars restrict overhead vision and window patterns further limit the view. A forward field of 30° probably covers most driving. The common binocular field averages 60° and spectacles provide fields of view from 40° to 60°. The macula of the retina subtends about 9°. A wide side vision may be less important at night as little can be seen at the edge of the field and additional clues are provided by the lights of cars approaching on sharply angled side roads.[4] Visual efficiency falls off rapidly away from the central fovea.

Measurements of road luminances made six years ago indicated that 4 ft-L is about the brightest and that little useful information was obtained from less than 0.003 ft-L at the edges of the road.[32] Recent data have fallen within these limits, Figure 2. The luminance along the center line of the new Hudson Road is reported within 2.3 to 0.4 ft-L and from 0.12 to 0.04 ft-L at 100 feet from the luminaries. The experimental lighting on the Connecticut Turnpike appears not to provide more than 1 ft-L. The IES Handbook[24] data indicated brightnesses of 0.018 to 0.35 ft-L for asphalt and 0.4 to 3 ft-L for concrete roads, depending upon the illumination and the condition of the roads. Drive-in screen luminances are reported to average about 0.4 ft-L with surrounds (when unlighted) of 0.003 ft-L. A pedestrian with a gray suit reflecting 11%, 350 feet away has a luminance of 0.012 ft-L and another with a brown suit reflecting 3% measured 0.016 ft-L at 100 feet ahead.[32] The pedestrian was less bright than the road and seen only in silhouette. (In this example, Figure 2, the pedestrian was brighter than the road when 25 feet ahead but darker than the road beyond about 50 feet ahead.) These values show that the eye uses low photopic and upper mesopic vision at civilian night driving levels and we may examine its efficiency under these conditions. Scotopic vision is *not* concerned at these luminances. Davey[5] reports dark adaptation levels of log $\overline{5}$.79 ft-L on a dark road of 0.7 to 0.2 ft-L, log $\overline{4}$.47 in the strand region of London and of log $\overline{5}$.17 ft-L in the country. Some five minutes would be required for the eyes to adapt from bright city levels to those in the country.

The rate and extent of dark adaptation depends upon the level at the beginning of the adaptation as well as the luminance concerned and the physiological state of the organism. Daytime exposures to intense sunlight raise the threshold at night, but this seems more important at lower luminances than those of civilian night driving. Nutritional deficiencies (especially vitamin A) from prolonged malnutrition, or a transient result of diarrhoea, etc., and diseases (endocrine, nervous system, uncontrolled diabetes, psychoses,[10] etc.) decrease the ability to adapt to lower luminances. Dark adaptation is reported slower at age ranges of 20-29 and 50-59, than at 30-50 and over 60.[27] Individual differences and variation amount to 0.2 to 0.3 log unit. Investigations by Weale and others indicate that nervous mechanisms may be involved in dark adaptation as well as chemical changes in the retina. Oxygen is about the only efficient stimulant to the dark adaptation process. Since low adaptation levels are not involved, tests for motorists need only measure the first ten minutes of dark adaptation. So far adequate, simple screening tests have not been developed and testing dark adaptation is mainly a laboratory procedure.

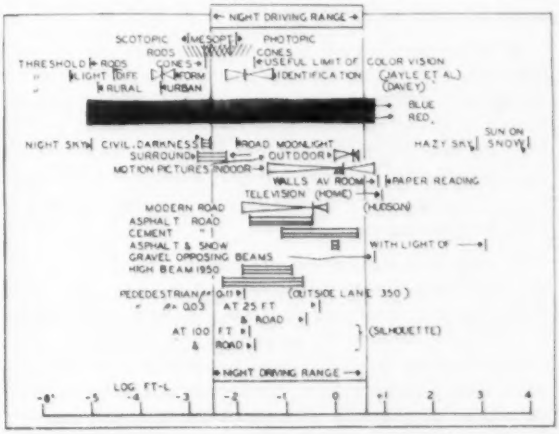

Fig. 2. Luminances of night driving and some information on vision at the indicated levels.

Night vision depends on more than dark adaptation although marked reduction in the ability to adapt could prevent safe driving. People with adequate ability should wait a few minutes when changing from a brightly illuminated room to a dark unlighted road, and those with less good adaptation should wait longer before driving. How to use the retina, muscular coordination, and focusing ability of the eye are important in night vision. Proper motivation and alertness are essential.

Graded transition lighting is necessary at tunnels, underpasses, and other regions where the luminances change more rapidly than the driver can adapt to the changes. Otherwise the strain on the driver, uncertainty, slowed responses are potential means for accidents. Proper gradations in lighting for daytime will usually not be the best for night driving. The knowledge and limitations of normal and deficient vision should be utilized when building and operating roadways.

The transition from cone to rod vision is gradual and color vision is lost at about 0.04 ft-L, Figure 2. At the lower driving levels reds become darker and blues brighter, but color cannot be expected to aid the motorist to see obstacles for other than the brighter road lighting. Traffic lights are usually bright enough to be seen when properly positioned against an adequate surround. Traffic engineers should be held responsible and given authority so that traffic signals are visible at night and not lost among colored advertising and other distracting lights. Color coded highway signs may be of little use and possibly even hazardous on dark rainy nights, unless they are made sufficiently large or properly reflectorized to be visible under adverse conditions.

No Colored Lenses at Night

Colored glass before the eyes reduces vision at night by about the same amount as the light absorption of the glass and should never be used for night driving.[22] Perceptual distance is shortened at lower luminances. At night, seeing and stopping distances become about the same at some speed (sometimes under 50 mph). At this point the loss of even a very little light from any absorbing glass may result in a rear end collision.

With average daylight small objects do not need to have high reflectivity or to contrast greatly with their surround to be seen and recognized. This upper limit for driving luminance is also about the same brightness at which people tend to turn on electric lights. Vision as expressed by standard observer curves at 0.01 ft-L is about 73% of what it is at 1 ft-L. Some of the changes in vision with less light are summarized in Figure 3.

On the highway, objects reflecting little light to the eye must contrast with the background, as contrast becomes more important after dark than acuity. Unless the difference in luminance between the pedestrian and the road is great enough for that level, the pedestrian will not be seen and when only slightly more visible he may not be seen within the seeing or stopping distance available to the motorist for the speed of driving. Actual measurements and common experience show that pedestrians in dark clothing are scarcely visible on the roads even when night seeing is optimal, and their visibility should be considered in the establishment of proper night speed limits for a given road.

Some years ago Luckiesh and Moss measured 150 people, found normal vision (20/20) at 10 ft-L, and a decrease in the average vision to 20/55 after adaptation to 0.01 ft-L. The person with the best vision at the lower level had only half of the acuity available at the higher level. This is less than the minimum for daylight driving in some states! Other measurements indicate that to obtain the same acuity at the lower level a sign must have letters five times larger. Contrast must also increase to six to twenty times to keep the same size sign legible at the lower brightness. This assumes, of course, sufficient time to see. In other words, for a given contrast there is a minimal size that can be seen.

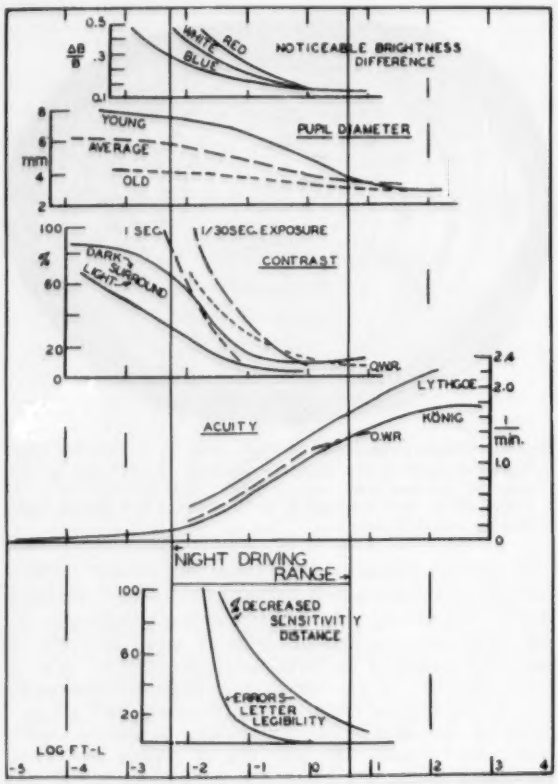

Fig. 3. Some aspects of human vision with decreased illumination. (From various sources[22]; fractional exposure contrast from Blackwell[5]; distance sensitivity from Hirsch and Weymouth, 1954, Am. J. Optom. 31:276; letter legibility from Fransworth, 1952, Med. Res. Lab., New Lond., Conn. Rept. 209.)

Seeing is limited by speed. Unless a minimum of light is focused on the retina for sufficient time there is no vision, and when the image moves faster than the eye can compensate, vision is impossible. For black and white seeing 1/30 second is said to be adequate, while 1/5 second is necessary for seeing color. Fast driving changes the blurring

so that smaller fields at greater distances in front of the driver remain clear. Danielson[3] reports that driving at rapid speeds is more comfortable when only the central field is clearly seen and the eyes shielded from the blurring of side vision. The loss of clues from the blurring at the side may lead to over-confidence and even greater speed. Roper found seeing distances to decrease by 20 feet for each increase of 10 mph. Vibration above 2-5 cps decreases vision[8] and the loss of vision at high driving speed increases from the greater vibration of the vehicle. At high speeds the estimation of movement and judgment of speed may be halved. The safe speed for a given driver is that wherein the perceptual load is not too great for proper response. At night this load is greater and speeds should be proportionately less. A driver with poor night vision may have to go so slow as to be a hazard on an express turnpike.

Seeing involves dynamic factors not found in a camera and blurred photographs taken from a motor vehicle should not be used to explain human vision since the camera blur can be made good or bad, by controlling the lens quality, focus, aim, shutter speed and film sensitivity.

What Is the Eye?

The eye is a viscous liquid system maintained at a nearly constant pressure and volume by interchange of nutrients and wastes with the circulatory system. It floats in the orbit against fat pads and muscles control its orientation, light input and focus. Muscles usually work against each other with graduations of shortening obtained by the use of fewer or more individual fibers within the muscle bundle. On a fine scale, the movement is oscillatory and the equilibria are dynamic.[1,2] This may be necessary, as the retina which translates the incoming light energy into nerve impulses, is a mosaic of rods, cones and connective tissues and holding the light image on the same retinal units leads to fading and invisibility. The small tremor movements utilize fresh receptors and adjacent regions making continuous vision possible. Other muscular movements correct these drifts and keep the view in the sensitive fovea. The oscillations of the focusing muscles aid the eye to the best adjustment as we look from one distance to another. The movements of the iris are stepwise and close observation will show also the volume changes from the pulse. The mechanisms are controlled by the nervous system and seeing efficiency depends on the response to changes from moment to moment in the amount and distribution of the light entering the eye. At night the changes in illumination can occur faster than the eye muscles can adjust the eye to the changes. The resulting conflict in the seeing mechanism and the strain of trying to get a clear and sharp view, which cannot be obtained under these conditions, is a source of strain, frustration and fatigue in the driver.

A sharp retinal image is perceived quicker and is less disturbed by glare light. A properly placed quarter diopter cylinder has been reported to improve night acuity by 25%.[12] Eyes looking into a monotonous field devoid of fixation objects tends to a focal position around 1 meter (empty field myopia). With less stimulating light at night a myopia may develop that can be explained partly by the increased spherical aberration accompanying the larger pupil and partly from the Purkinje shift, which is a gradual change from detailed cone mediated vision, to the pattern vision at low intensity from the rods. The change begins within the luminances of civilian night driving, but the driver's eye does not reach scotopic levels when nothing can be seen at the rod free fovea (physiological central scotoma).

Variations in Night Myopia

Not all people show a night myopia at driving levels and I have found an occasional person who sees better at these levels with a small plus rather than minus add. A low grade hypermetropia may become essentially emmetropia as a result of the night myopia, but a myopia is worsened, especially when handicapped by inadequate undercorrection. At night driving levels some people can see better with —0.50 to —1.50 diopters additional correction, but tests have shown that there is no universal prescription and that too many would see less well to justify any such procedure. While a hypermetrope may see better without his spectacles when his far-sightedness and night myopia are about the same, this should be permitted only when the spectacle correction is free from cylinders or prisms.

Another problem is aniseikonia where unequal imagery, when not corrected, provides a distorted world that disturbs driving. With good lighting and familiar objects these distortions are less important, but unfamiliarity or freedom from known clues (as in the leaf room) brings them out. Likewise, aniseikonia disturbs night driving more than daylight driving because of the lack of clues and the unfamiliar appearance of objects. Little is known as to the extent of these effects and screening for aniseikonia would be worthwhile, since this anomaly can be a problem in auto driving. A change in prescription may lead to an accident, as the case reported by Morrison[29] where the patient said the spectacles were comfortable but it was difficult for him to keep in the right part of the road, a trouble attributed to aniseikonia.

Morrison[29] also recommends that persons do not drive for some time after receiving their first spectacles. Newly corrected myopes tend to brake too quickly, while hypermetropes brake too slowly, both of which are unsafe. When a change of prescription is likely to require some getting used to, it should be the obligation of the optometrist to warn the patient and aid him to understand the process. Driving, or night driving, may be contra-indicated for a time.

The loss of an eye requires compensatory care while driving, but driving does not seem to be unduly hazardous when the remaining vision is good.[19]

Color vision plays only a small role at night. Traffic lights are bright enough to be differentiated; likewise reflectorized signs, but colors should not be expected to assist driving. At the lower levels of road illumination colors are seen as grays varying only in brightness.

High acuity is unnecessary for daytime driving when the pupils are small. There are reports of accident-free driving with low acuity, even 20/400, with no great difficulty after the first five minute adjustment. At night this is no longer true; the weak blurred images do not have enough contrast for seeing and the driver may not see obstacles. Motorists with less than 20/20 daylight vision should drive more slowly at night than those with better vision, and the proportionate decrease in speed should be determined for a representative section of the driving public.

Aging decreases vision along with the other changes of senility. More light is necessary for seeing with the smaller pupils and failing system. One study indicates that for equal seeing the light needs to be doubled for every thirteen years of age.[11] Figure 4 summarizes other information showing how vision decreases with age. Acuity and contrast sensitivity decrease and the decreases may result in lower levels than are legal for driving in some states. This is another reason for a reconsideration of the importance of Snellen acuity as a criterion for a driving license. Since the available luminance is scarcely adequate for the best eyes, many older people should drive less rapidly and essential signs and signals should be much larger and brighter than those required for the best young eyes. Fortunately, older people generally become more conservative and drive more carefully. The professional responsibility of the ophthalmologist and optometrist is more important with the older patient, who needs spectacles that help as much as possible and perhaps also advise on when not to drive at night. Opacities forming in the eye reduce vision to an unsafe level. The vision specialists have the problem of determining what is an unsafe level and advising the traffic engineers and the lawmakers so that better highways can be made and safely operated.

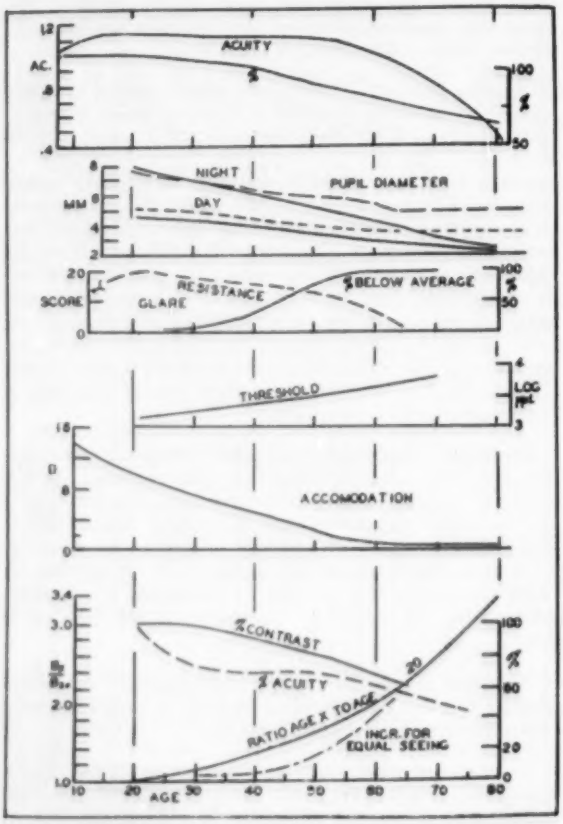

Fig. 4. Some age changes in human vision. (From various sources[22]; bottom curve from Guth.[11])

Efforts to See Increase Fatigue

Fatigue increases when seeing involves intense effort. More muscles are involved with difficult seeing, such as those of the brow and even cheek and lip muscles. When these changes lead to general body tension, beyond an alert relaxedness, still more fatigue can build up. Weston[41] states: "Conditions of lighting which are suboptional for particular visual tasks accelerate the onset of fatigue occasioned by seeing, chiefly because they necessitate undue muscular exertion in getting the required visual information, but also because they necessitate undue mental 'exertion' for the processes of interpretation and discrimination." The fatigued driver needs greater stimulation for proper response. Since such increase is not possible with the very small illumination (as compared with daylight), the fatigue increases and seeing becomes worse. In cities, or at some intersections, the large numbers of lights may overstimulate the tired driver and the lone traffic signal may not be perceived, while on lonely country roads there may not be stimuli enough to keep a tired driver awake.

Seeing at night may be worsened or even eliminated by adverse weather, dust storms, heavy rain, or dense fog. The field of view is impoverished, objects are less visible and vision is distorted by the streaky, dark surfaces that tend to camouflage silhouette seeing. Improvements in illumination promise some help, but the eyes cannot function without light and we have to make the best of a poor situation.

Glare from oncoming headlights can reduce night driving vision, especially when rapidly repeated from a succession of cars on a narrow curving road. The effects and mechanism are well known; a general veiling and reduced contrast. I have seen no so-called night driving glasses which solve the problem. The most successful aids are screens which block out only the glare sources, but do not steal light from the rest of the field of view. A red segment in the upper left can be used to decrease glare by tilting the head slightly so that the oncoming lights are in the segment, because red light does not spoil the dark adaptation, and limiting the red to a segment leaves the rest of the road in unobstructed view. Holding the hand over one eye or even shutting one eye will protect that eye from the glare. As soon as the car passes the protected eye is used and the other one closed until the after-images subside. The discomfort from intense glare may be due to the irregular behavior of the iris to respond to areas of the retina calling for more light and others calling for cutting down the

glare light. The adverse effect of glare depends on the amount and location on the retina. Hopkinson attributes the complaints of myopes on glare sensitivity to the dazzle from the flashing of the edges of the thick lenses, a difficulty not found with plus lenses.[23] Lighting or making spectacle frames luminous, and other devices to raise the retinal adaptation level must and do fail to help the motorist, because the resulting glare reduces vision and the higher adaptation level may be too great for him to see the roadway details.

The illumination engineers treat glare as an overall veiling brightness and Boynton[19] has demonstrated this glare experimentally. Other investigators find the effect of glare to depend also on the nature of the visual task. My own experience shows the annoyance from glare to depend more on having the proper correction so that the lights are imaged most sharply on the retina. This can be done for me with a 20/15 day correction or a proper minus fitover for a less good daytime correction. I urge correcting myopes fully, unless there is a specific reason for not doing so.

Glasses Handicap Drivers

The motorist who must wear spectacles is handicapped when compared with the driver not needing such aids. Unless the surfaces are coated some 8% of the light is lost from surface reflections. Should this light reach the eye it is a source of annoyance as veiling glare or even a dangerous distraction when the reflections are nearly in focus.[40] Such reflections show better at night. I remember wearing a pair of cemented doublets for aniseikonia that made safe driving on a street, with cluster lights at each side, almost impossible until the inside surfaces were coated to eliminate the reflections. Therefore, optometrists should use extra care in prescribing and fitting spectacles for those who drive. Not only should motorists be given the best vision possible but the most comfortable spectacles, free from reflections, properly tilted and with the segments placed so that interference is least. When such a pair cannot also meet occupational requirements and the patient does considerable driving, another pair is needed. Those concerned with operating our roads are concerned with driver comfort, because the irritated driver is a potential source of accidents. Ill-fitting spectacles may upset a driver and having to tilt the head unduly to see the road above a trifocal segment can be enough annoyance to become the disturbance that triggers an accident.

There seems to be no point in discussing whether or not vision is a contributory cause of accidents—no one drives long with his eyes shut. If we knew enough about motorists' seeing ability at night, the excess number of night accidents would be largely explained. The decreased seeing at night and reasons for it summarized in this paper are general. The individual driver may be much better or worse than the average and is entitled to the judgment of his peers; here the responsibility falls on the vision specialist.

The recent training and rules proposed for better daytime seeing and driving suggest that proper training for night seeing should help. The following rules are offered as a beginning:

1. Take enough time to get used to seeing (adaptation) when leaving a bright place before starting to drive at night. Drive slower during transition from bright lighting to little or no lighting.

2. Relax the eye muscles by looking about as much as safe driving permits. Never stare for long at the same region.

3. Protect the eyes from glare. Look to the side of the road rather than at a glare source. Insist on dimming high or bright lights.

4. At night never wear sunglasses, or tinted spectacles, that have absorption over the entire field of view. Absorption in a small region at the left or upper left may be useful, but the road in front of the driver must always be clear.

5. Keep spectacles, windshields and lights clean and free from surface damage that reduces their transmission.

6. Slow down until the perceptual load is not too great for good, safe driving.

Optometrists and other vision specialists must consider night driving problems and deficiencies so that they can provide the professional care for the best possible seeing. This will ultimately bring forth other criteria than static acuity and may even lead to specialized examining methods to evaluate vision when the lighting cannot be quite enough. From the vision viewpoint we must insist on improved road and car lighting, more readable signs and signals, and other aids to relieve the extra load on night seeing. Driving includes much more than seeing and other experts must cooperate with the vision specialists toward making better use of the information gathered by the eyes of the driver and for better vehicles and roadways.

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EFFECTIVENESS OF A DRIVING SIMULATOR

by Earl Allgaier
and
Samuel A. Williams

Summary

Two driving simulators, the AAA Auto Trainer and the Aetna Drivotrainer are now used in a number of high schools scattered throughout the country. In this study, four Auto Trainers were used in a high school for two years (1956-58). The control group of 99 students had a conventional driving course, including about 5.74 hours of behind-the-wheel practice driving. The experimental group of 158 students received 3.69 hours of behind-the-wheel practice and 5.74 hours of practice on an Auto Trainer.

The two groups did equally well on a comprehensive road test given at the end of the course, indicating that about six hours of Auto Trainer practice were equivalent to two hours of behind-the-wheel driving practice. With the use of the Auto Trainers, the instructor was able to teach one-third more students per period.

Introduction

High school driver education has come a long way since its humble beginning about 1936 when the number of high schools involved could probably be counted on the fingers of one hand. It is estimated that during the 1957-58 school year nearly 600,000 students received at least 30 hours of classroom instruction and 6 hours of practice driving in courses offered by over 9,000 high schools.

During the first two decades (1936-1956) of driver education, it is estimated that nearly 3,000,000 students have received instruction and, because of this instruction, the following results have been achieved: (1) 2,800 lives saved; (2) 98,000 injuries prevented; and (3) an economic loss of nearly $300,000,000 prevented. Thus, about $100 has been saved for each student trained. It is true that these are only estimates, but they are based on the best information available. In addition to the results attained in the prevention of economic waste and physical suffering, it is hoped that these courses will do much to develop better citizens for tomorrow.

What price must we pay for this program? Several surveys based on reports from hundreds of high schools have been made to determine the out-of-pocket costs per student trained. These costs include teacher's salary, car maintenance and operation, text materials and testing and training aids. The table below summarizes this information for three school years and shows the cost of the instructor's salary.

Cost of Driver Education per Student

School Year	*Total Cost per Student*	*Instructor's Salary Only*	
		Amount	*% of Total*
1949-50	$33.71	$30.20	90%
1952-53	31.14	26.01	84%
1954-55	33.32	28.51	86%

Today the people who do not believe driver education is a worthwhile course are few and far between. However, as is true of other worthwhile subjects, driver education must compete for its share of the high school operating budget. School administrators, looking for ways to balance the school budget, are likely to look first at those courses with a high cost per pupil regardless of the merits of the course. Consequently, anything that can be done to reduce this cost will help to keep the subject in the curriculum.

It is obvious from a quick glance at the above table that by far the largest part of the cost is for the teacher's salary. The chief hope for reducing the per pupil cost, therefore, lies in the development of methods which will enable one teacher to train more students *without* in any way lowering the quality of instruction. Classroom instruction is no problem since the class size may be as large as a class in mathematics or English. However, when behind-

the-wheel instruction is given, the instructor can actually instruct only one student behind-the-wheel at a time. Obviously, the way to increase the number of students trained per teacher is to reduce the hours of instruction for each student or devise means whereby one instructor can supervise the practice of several students simultaneously. In general, most students are now receiving only the bare minimum of practice driving, so the only alternative is to devise means whereby one instructor can supervise the practice of several students at one time. Several methods of doing this have been used but none have been generally adopted.

Reducing the per Pupil Cost

Multiple car plans, such as used in Pershing High School in Detroit and Lane Technical High School in Chicago, use an off-street practice where the instructor supervises the practice of several students each driving a car simultaneously. Usually a student with some experience rides beside the beginner who is behind the wheel.

In some cases, student assistants, school bus drivers and others receiving lower salaries than the regular driving instructor have been used to instruct beginners under the general supervision of the regular driving instructor. Such methods, however, tend to lower the quality of instruction.

One method which seems to have considerable merit is the use of driving simulators. These are not new in the driver education field, but the extensive use of simulators of various types during World War II did much to increase their prestige and public acceptance. In the field of driver education, simulators go back at least to 1928 when Dr. A. R. Lauer, then at Ohio State University, developed a "Coordination Apparatus" which was essentially a steering test.

Further development by Dr. Lauer resulted in the "Drivometer" in 1930. This involved a roadway painted on a revolving belt, the speed and direction of which were controlled by a transmission and variable speed motor. A small car was guided on this roadway by means of a steering wheel. In 1936, Lane Technical High School built 30 "dummy cars" for use in a classroom. Each unit had a steering wheel, gearshift lever, accelerator, brake and clutch with switches which controlled a panel of lights visible to the instructor. In this way, the instructor could show a traffic film and, by observing the panel of lights, detect any student not operating his controls correctly. During 1936, the Automagraph Company began the development of a trainer using a continuous film with dummy controls and keyed to recording apparatus so that the reactions of the driver could be recorded on paper.

As a result of this basic development over the past two decades, two types of simulators have evolved that are now being used in a number of schools scattered throughout the country. One of these is the "Drivotrainer" which was developed by the Aetna Casualty and Surety Company and is based largely on developments made by the Automagraph Company. It involves a movie projector with traffic films, a number of dummy cars with the usual controls and equipment for recording the manipulations of the controls as the film progresses. The vehicle controls in no way affect the traffic scene but do operate switches so that each student's response to a given traffic situation is recorded on paper.

The other simulator used in a number of schools is the "Auto Trainer" developed by the American Automobile Association and patterned after the Drivometer developed by Dr. Lauer. A miniature roadway is painted on a revolving belt two feet wide and ten feet in circumference. A variable speed motor drives this roadway backward or forward through a clutch and standard transmission. A miniature car (10" long) rides on this roadway. The front wheels are steered by a full-sized steering wheel. With this mechanical arrangement, the student can practice many of the basic maneuvers involved in learning to drive such as starting the engine, shifting gears, steering forward and backward, driving forward and backward, parallel parking, stopping, etc. Obviously the Trainer does not have the realism of a regular car. Also, the effect of other traffic cannot be simulated.

Purpose

The primary purpose of this study was to determine if practice on the Auto Trainer could be substituted for some of the behind-the-wheel driving practice without reducing the quality of instruction as measured by a road test of driving ability at the end of the course.

Control and Experimental Groups

In order to avoid any artificial situation, this research project was superimposed on a regular driver education program which was already in operation at Anacostia High School, a school of about 2,000 students. The study covered two school years—1956-57 and 1957-58. Normally the instructor taught five or six classes of about ten students each during each semester. For example, a first period class met five days a week. After several days of classroom instruction, the instructor took four students at a time in a car to give behind-the-wheel instruction. The remaining students stayed in the classroom to study text material or practice on the Auto Trainers. For each semester the largest classes were arbitrarily put in the experimental group and the smallest classes were put in the control group. The control group was to receive the regular behind-the-wheel practice driving and no practice on the Auto Trainers. The experimental group was to receive practice on the Auto Trainers but less behind-the-wheel practice. The largest classes were selected for the experimental group since it was obvious that the instructor could teach more students if each student were to be given less behind-the-wheel practice.

Nature of Instruction

Insofar as practical, both groups received the same classroom instruction. Four Auto Trainers were used by the experimental group. The instructor demonstrated each lesson on the Trainer, then supervised the students for some practice. However, most of the practice on the Trainers was done while the instructor was giving instruction to four students in a car.

Nature of the Two Groups

Since the control and experimental groups consisted of students already assigned to classes without any known selective factors operating, the groups were not necessarily matched with respect to the major factors which might affect final driving performance. Because of this, numerous tests were given and biographical data recorded to detect any differences in the two groups which might distort the final results. The following information was obtained for all students at the beginning of each semester and comparisons made between the control and experimental groups to determine any differences which might be significant:

1. Sex
2. Age
3. Grade in school
4. Hours of driving experience
5. Years of bicycle experience
6. Hours of steering practice while another drove
7. Whether the family owned a car
8. Knowledge of driving—25 question test
9. Attitude—Siebrecht test
10. General aptitude—Otis test
11. Field of vision test
12. Color vision test
13. Distance judgment test
14. Visual acuity test
15. Reaction time test
16. Steadiness test
17. Night vision test

The scores for each semester were analyzed. Where there was a significant difference on any score between the control and experimental groups, this score was correlated with the road test to see if there was any significant relationship. The few instances where there was a significant difference are summarized below.

During the first semester, a larger percentage of the experimental group had over 8 hours of driving practice before taking the course than did the control group. Previous studies have shown that students with more home practice do better in a driver education course. The experimental group had a slightly higher intelligence rating. This correlated .2460 with the final road test. The control group had more classroom instruction. The correlation between classroom instruction and the final road test was negative and insignificant.

During the second semester, the control group had a larger percentage of boys and boys made significantly better scores on the final road test. The experimental group averaged 0.4 year more education. Students with more years of education did better on the final road test. ($R = -.27$).

For the third semester of the study, the experimental group reported more practice steering while another person drove. Those who had more of this practice did better on the road test. ($R = -.27$) The experimental group also did better on the steadiness test but there was no relationship between the steadiness score and the road test.

During the fourth semester, the experimental group had a higher percentage of boys and boys did slightly better on the road test but not significantly so. The control group had a higher percentage of students with 8 or more hours of practice driving prior to the course and students with this home practice tended to do better on the final road test.

From the above, it is apparent that when the groups for all four semesters are considered, the control and experimental groups are substantially equivalent. This should be the case since no known selective factors were at work when the students were assigned to the driver education classes.

At the end of each semester, a comprehensive road test was given to each student by a qualified examiner who had no connection with the school. In each case the examiner had no knowledge as to whether the student was in the control or experimental group. It will be noted that for the first semester the experimental group did better while the control group did better for the last three semesters. However, the differences are so small that they are of no statistical significance. The results are summarized in the *Comparison of Control and Experimental Groups,* Table I.

Performance of Two Groups on Final Road Test

A road test check list of 135 possible errors was used to check each student on the final road test. Since the same examiner gave all the tests for the last two semesters, the results were combined and are presented graphically in

FIGURE 1

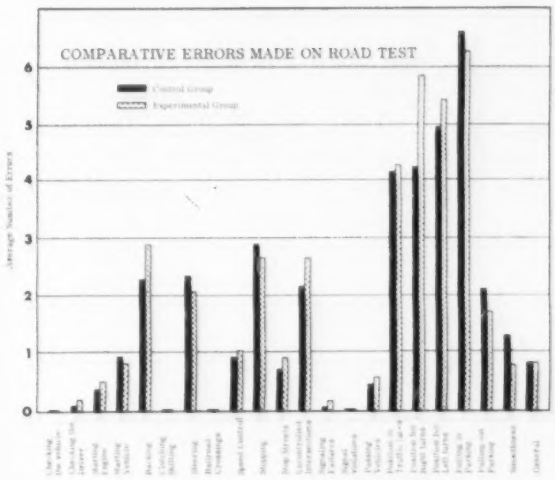

Fig. 1. From visual observation it is evident that there is no material difference between the performance of the two groups. This was confirmed by a chi square analysis which indicated also that there was no statistically significant difference between the two groups.

In other words, the practice on the Auto Trainers by the experimental groups was about equivalent to the extra practice behind-the-wheel received by the control group.

In Table I it will be noted that the experimental group had 2.05 fewer hours of behind-the-wheel practice but had 6.10 hours of practice on the Auto Trainer. This gives a ratio of about three to one.

If it is assumed that the final road test score is dependent upon the hours of practice driving and hours of Auto Trainer practice properly weighted, it is possible to solve simultaneous equations for each semester to determine the number of hours of practice on the Auto Trainer which are equivalent to one hour of practice driving. The equivalent values are as follows:

1st Sem.—3.96 Hrs. on the Auto Trainer equal 1 Hr. of Practice Driving

2nd Sem.—1.86 Hrs. on the Auto Trainer equal 1 Hr. of Practice Driving

3rd Sem.—3.88 Hrs. on the Auto Trainer equal 1 Hr. of Practice Driving

4th Sem.—1.48 Hrs. on the Auto Trainer equal 1 Hr. of Practice Driving

Since the study was conducted under normal school conditions insofar as practical, no attempt was made to keep the amount of instruction exactly equal for the various classes. Variations were due largely to differences in class sizes and the availability of a dual control car. However, these are variations which will usually be encountered in practice.

More Students Trained per Period with Auto Trainer

Since the study was conducted primarily to determine if practice on the Auto Trainer could be substituted for behind-the-wheel practice, no special effort was made to determine how many more students could be taught per period when the Trainers were used. During each semester the largest classes were put in the experimental group since the teacher would not have to spend as much time with each student in a car. As a result of this selection, there was an average of 9.9 students per class in the control group and 13.2 students per class in the experimental group, or an increase of 33%.

Intelligence and Driving Knowledge Related to Driving Ability

As a by-product of the study, numerous correlations between various factors were computed. Most of these were insignificant. A few of the larger correlations are given in Table II.

TABLE II

Intercorrelations between Various Factors

	Semester 1st	2nd	3rd	4th
Jerk Recorder (measures jerks while driving) vs Final Road Test	—	.45**	.45**	.64**
General Aptitude (Otis test) vs Driving Knowledge Test	.67**	.32**	.40**	.47**
Driving Knowledge Test vs Final Road Test	.45**	.27**	.25*	.25*
Reaction Time vs Final Road Test	.48**	.34**	.13	.19
Years of Bicycle Experience vs Final Road Test	.45**	.30**	.07	.18
General Aptitude (Otis test) vs Siebrecht Attitude Test	.42*	.03	.28**	.15

*Statistically Significant **Highly Significant

As would be expected with small groups, there is considerable variation from semester to semester. However, it is quite evident that general intelligence and driving knowledge at the beginning of the course are substantially related to performance on a road test at the end of a course.

Another interesting correlation is that between the jerk recorder reading and the road test. The jerk recorder is a simple device for measuring excessive acceleration and deceleration. The coefficients are substantial and about as large as the correlation you would expect between road test scores obtained by two examiners testing the same group of drivers. In a sense, the jerk recorder measures a driver's ability to anticipate traffic conditions and thus avoid the necessity for sudden starts and stops.

TABLE I

Comparison of Control and Experimental Groups

Semester	Group	Students in Group	Hours of Instruction: Classroom	Practice Driving	Auto Trainer	Road Test Score*	Significance of Difference of Road Test Scores P**
1st	Control	21	32.0	5.67	0	+ 18.4	86
	Experimental	29	26.5	4.07	7.8	+ 19.6	
2nd	Control	17	17.7	6.7	0	— 30.9	68
	Experimental	42	17.2	4.0	5.75	— 32.7	
3rd	Control	28	27.9	4.7	0	—104.3	43
	Experimental	41	29.6	3.5	5.72	—110.3	
4th	Control	33	23.2	5.9	0	—128.0	23
	Experimental	46	22.1	3.2	5.14	—145.1	
Aver. of 4 Semesters	Control	99	25.2	5.74	0		
	Experimental	158	23.8	3.69	6.10		

* A negative sign indicates a larger score is a poorer score.

**P indicates the chances per 100 that a difference in a road test score this large would occur by chance.